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Stellar Distances*

By FREDERICK SLOCUM

Volumes have been written and are still being written on this subject which has been assigned to me. An adequate discussion of it in the time at my disposal is impossible, so I shall limit myself to a survey of some of its phases with which I am most familiar.

The principal method of finding the distance of a star is by means of its parallax. Aristotle, in the fourth century B.C., frequently uses the word parallaxis in the sense of a slight relative change, especially a change in direction. For example, he argued that the earth could not be moving in an orbit, for, if it did, the stars would appear to be in slightly different directions when seen from opposite sides of the orbit, or, more specifically, the nearer stars would appear to shift their positions with respect to the more distant stars in a period of exactly one year. Aristotle could detect no such parallax so he concluded that the earth must be fixed.

Aristarchus, a century later, reversed the argument, claiming that the earth does revolve around the sun, and that the stars do have a periodic shift in apparent position, but that they are so far away that the shift is imperceptible. That is, there is a definite relation between the parallax and the distance. It is customary to use for the parallax, not the maximum displacement of the star, but rather the difference between the direction of the star as seen from the earth and from the sun, or, what amounts to the same thing, the angle at the star subtended by the mean radius of the earth's orbit. It is this angle that I shall refer to as the star's parallax. If this can be measured the distance can easily be computed by trigonometry.

However, for two thousand years after the time of Aristarchus no one succeeded in detecting any parallax. Hipparchus and Ptolemy assumed the earth to be fixed and explained by a system of deferents and epicycles the apparent motions of the planets, which are really due to the relative motions of the earth and planets.

Copernicus in the sixteenth century adopted the heliocentric theory, assuming with Aristarchus that the parallax was too small to be measurable. Tycho Brahé, the Dane, at his great observatory on the island of Hven, developed instruments of far greater precision than had been attained before, and yet even he could find no parallax. This led him

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to reject the Copernican theory, but a few years later Kepler and Galileo obtained convincing proof, independent of parallax, that the earth must be moving in an orbit, and Galileo went so far as to advocate a method of measuring the effect of this orbital motion. With his little telescope he had discovered many double stars. Some of these differed greatly in magnitude. He naturally inferred that the brighter is nearer than the fainter and, therefore, should show an annual periodic shift with respect to the fainter. His telescope, however, was not powerful enough to detect it.

During the next century meridian circles were developed and Flamsteed, Picard, Cassini, Halley, and Bradley all tried for parallax without success. Halley discovered proper motions of a few stars and suggested that the size of the proper motion might give some clue to the nearness of the star.

Bradley at Greenwich made many observations of Gamma Draconis, which passed near his zenith. He discovered aberration and nutation, two important by-products of the parallax program, but he got no parallax. He claimed, however, that if the star had had a parallax of as much as one second of arc, he could have detected it. This means that the star must have been at least 200,000 times as far away as the sun.

Sir Frank Dyson in his Halley Lecture makes this interesting summary of ideas in regard to stellar distances down to the end of the 18th century. Before the use of instruments, say before the time of Hipparchus, about 150 B.C., with the naked eye it would have been possible to detect a relative displacement of stars about equal to the apparent diameter of the moon. This would correspond to a parallax of half that amount or fifteen minutes of arc. A star with that parallax would be about 200 times as far away as the sun. No such parallax was found, so it could be inferred that the stars are at least 200 astronomical units away.

With the best of the instruments in use before the telescope, for example, the instruments of Tycho Brahé, it should have been possible to measure down to somewhat less than two minutes of arc, pushing the lower limit of the distances of the stars out to 4000 astronomical units. With the telescopes of the 18th century this limit was extended to 20,000 astronomical units and with Bradley's meridian circle to 200,000 astronomical units, about eighteen million million miles, and still no parallax could be detected.

Near the end of the 18th century Herschel attacked the problem. He followed Galileo's suggestion to measure double stars in which the components differed greatly in magnitude. For this purpose he used one of his large reflecting telescopes and an ingenious micrometer that he had invented. He found changes in the separation and direction in some of the pairs, but the changes were not annual. They were progressive, that is the stars were revolving around each other, binary stars, he called

them, and they were, of course, at approximatly the same distance. Difference in brightness, then, is not necessarily an indication of difference in distance. In the course of this work he also discovered the planet Uranus. Here are three more additions to the many by-products of the stellar parallax program.

By the early part of the 19th century the equatorial mounting with clock drive was coming into use, largely due to Fraunhofer of Munich. This, with the heliometer, and filar micrometer contributed materially to the ease and accuracy of observations.

In 1838, just over a hundred years ago, came the announcement of the first positive parallax results. At about the same time, Bessel, in Königsberg, using a six-inch heliometer, found a parallax of 0″.31 for 61 Cygni; Struve in Dorpat with a filar micrometer on an eight-inch refractor obtained a parallax of 0″.26 for Vega; and Henderson, at the Cape of Good Hope, with a meridian circle, derived a parallax for Alpha Centauri of about one second.

Those results stimulated many others to undertake parallax determinations, among them Peters, Auwers, Krueger, Otto Struve, Brünnow, and Ball. A few, and only a few positive parallaxes were obtained. The observations were long and tedious, and, in most cases, the results were discouraging. The heliometer seemed best suited to the work and several were constructed and put to this use. A four-inch and a seven-inch were used by Gill, Elkin, and others at the Cape of Good Hope, to derive 26 parallaxes by the end of the 19th century. Peter at Leipzig with a six-inch measured 20 stars, and Elkin, Chase, and Smith at Yale with a six-inch heliometer derived 246 parallaxes between 1884 and 1912.

Meanwhile Kapteyn at Leiden had introduced a new method of finding parallaxes with a transit circle. Instead of trying to use absolute positions, he measured the difference in right ascension between the parallax star and some faint background stars. He was followed in this method by Jost, Flint, Grossmann, Voûte, and others, but, soon after the beginning of the present century, all earlier methods were dropped in favor of photography.

Pritchard of Oxford, Bergstrand of Upsala, Kapteyn in Leiden with Donner in Helsingfors, Russell and Hinks in Cambridge, England, and Jacoby and others at Columbia, all did good pioneer work along this line, but the real father of modern parallax work is Schlesinger, working first at the Yerkes Observatory, then at Allegheny, and finally at Yale. His classic papers on the subject appeared in the *Astrophysical Journal* for 1910 and 1911. The possibilities of accurate measurement of star images on plates taken either with photographic or with visual telescopes of relatively long focal length was recognized at once, and a number of observatories made parallax work the main feature, or a prominent part of their program. In his latest parallax catalogue, 1935, Schlesinger lists the following observatories as contributing most to that work: Allegheny, McCormick, Yale, Yerkes, Mt. Wilson, Greenwich, Sproul,

Bosscha, Van Vleck, and Cape of Good Hope. Nearly all of these are following essentially Schlesinger's original method, so it will suffice if I describe our procedure at the Van Vleck Observatory.

The problem is, of course, just like that of the surveyor who wants to find the distance of an inaccessible object. He measures off a base line, then gets the direction of his object from each end of the line. This gives him a triangle with one side and two angles known. By trigonometry, the other two sides, that is, the distance of the object from either end of the base line can be computed.

In our case the base line is the diameter of the earth's orbit, 186,000,000 miles, and in order to make our observations from the opposite ends of this diameter we must wait six months while the earth carries us half way around its orbit. Even with this enormous base line the maximum displacement, that is, double the parallax, for the nearest star is only about one and a half seconds of arc, and, for more distant stars, the parallax will be correspondingly less. The problem, then, is the exceedingly delicate one of deriving very small angles from observations subject to many possible errors. This requires a telescope of excellent quality and relatively long focal length.

At the Van Vleck Observatory a 20-inch refractor of 27.6 feet focal length is used. Since this is a visual telescope, a yellow filter is used in connection with photographic plates sensitive to the yellow color. The filter is mounted in the plate holder almost in contact with the film of the plate.

To avoid errors due to differential refraction, atmospheric dispersion, flexure, etc., all plates are taken as near as possible to the meridian. In order to secure perfectly circular star images on the plate great care must be taken with the guiding of the telescope during the exposure. This is done by means of a diagonal eyepiece near the upper edge of the plate. This eyepiece is moveable with a range of five inches east and west and one inch north and south. Within these limits we can generally find a guiding star of tenth magnitude or brighter. An illuminated cross of spider threads in the eyepiece is placed on the guiding star and held there by turning screws which move, not the whole telescope, but just the frame carrying the plate holder. The driving clock is supposed to move the whole telescope so as to counteract the rotation of the earth, but slight irregularities in the rate of the clock or displacements due to atmospheric effects must be corrected by hand guiding.

If there should be any tendency for the stars to drift in one direction, the constant work necessary on the part of the observer in bringing the guiding star back to the cross threads will cause the bright stars to leave a photographic record of each little departure and so build up somewhat pear-shaped images, whose center of gravity will be displaced with respect to the center of images of faint stars. It is, therefore, essential to have all the stars that are to be measured as nearly as possible of the same magnitude. If the parallax star is brighter than the comparison

stars, its light may be cut down by means of an occulting sector. The opening of the sector may be varied so as to reduce the light of the star from about one to six magnitudes. For still further reduction we use a filter which has near its center a neutral colored disk that will absorb about six magnitudes. This may be used in connection with the rotating sector, so that the image of Sirius, for example, will look like that of a tenth magnitude star.

The parallax star is located near the center of the plate and an exposure of from a few seconds to a few minutes will generally be sufficient to yield several other stars scattered over the plate. From three to six stars of about the same magnitude and as nearly as possible symmetrically located with reference to the parallax star are selected as reference points from which to measure the real or apparent motions of the parallax star. Generally two exposures are made on each plate, the images being separated by two millimeters.

The maximum parallactic displacement occurs when the star is 90° east or west of the sun. It is, of course, not always feasible to secure photographs at exactly such times, so it is generally necessary to use displacements that are somewhat less. The parallax factor, that is, the fractional part of the maximum displacement for any particular time can easily be computed. It is our practice to use plates with parallax factors down to $\pm$ 0.60. This means that we can take plates in the evening from dark until about 9:30 P.M., and in the morning from about 2:00 A.M., until dawn.

In order that the relative displacement of a star due to parallax may be clearly separated from that due to its proper motion, it is advisable to extend the observations over two or more years, taking groups of plates at intervals of about six months. We have set as our minimum, twenty plates, four at each epoch for five epochs.

The plates are measured by a microscope moved by a very accurately cut screw. In spite of all precautions the measures of the several plates will be affected by differences in scale, in orientation, in atmospheric effects, etc. To eliminate these, all plates are reduced to one plate as a standard, using Schlesinger's method of "dependences."

After this has been done, the remaining differences in the micrometer readings for the parallax star will be due to proper motion, parallax, and accidental errors in measurement. The proper motion is progressive, varying directly with the time. The parallax is periodic, varying back and forth annually and in proportion to the parallax factors for the individual plates. The separation of the proper motion and parallax involves a simple least squares solution of some twenty or more equations with three unknowns.

The resulting parallax will be the parallax relative to the faint comparison stars, which themselves possess small parallactic displacements. By statistical methods the average parallax of the faint stars of the various magnitudes is known, and this average added to the relative

parallax will give the absolute parallax, that is the real difference in the direction of the star as seen from the earth and from the sun. With this angle and the base line, the distance may easily be computed. It is customary, however, to leave the result in terms of the parallax.

If the distance is desired it may be expressed in many different units. The simplest is the astronomical unit, the mean distance from the earth to the sun. A parallax of 1".00 would correspond to a distance of 206,265 of these units; 0".10 to ten times this figure, etc. To change this to miles, simply multiply by 93,000,000. This will give too large numbers to handle conveniently so other units are used, such as the "light year," "parsec," etc.

The light year, as the name implies, is the distance that light travels in a year. In miles this would be found by multiplying the speed of light, 186,000 miles per second, by the number of seconds in a year. This gives about 5.8 million million miles. If a star had a parallax of 1".00, it would be at a distance of eighteen million million miles or 3.26 light years, whence the formula:

$$\text{Distance in light years} = 3.26/p$$

where p is the parallax of the star in seconds of arc. The parsec is the distance corresponding to a parallax of 1".00 and,

$$\text{Distance in parsecs} = 1/p.$$

Other units have been suggested but are now rarely used.

The results obtained by the method outlined above are called trigonometric parallaxes. This method has its limitations. For the very distant stars the parallax is too small to be measured accurately on photographic plates. The limiting value is probably of the order of 0".01, the angle which a foot rule would subtend at a distance of 4000 miles, or, on the scale of our photographs, corresponding to about one sixty-thousandth of an inch. We record our measures down to a ten-thousandth of a millimeter, or a two-hundred and fifty-thousandth of an inch, but we don't put much faith in the last figure.

With this limitation in mind we put on our observing program those stars which we have reason to believe are relatively near, and for this, Halley's criterion of proper motion is generally used. Our list is made up chiefly of stars not fainter than the 13th or 14th magnitude, with proper motions of 0".50 or more. In addition to these we have observed, or are observing, a variety of stars of especial interest; some of the very brightest stars, stars on the Mt. Wilson interferometer program, white dwarfs or suspected white dwarfs, a few binaries, variables, novae, and planetary nebulae.

The fact that trigonometric parallaxes are unreliable below 0".01 does not mean that our knowledge of the distances of the stars is limited to those within 100 parsecs or 326 light years. Distances may be found in other ways.

An excellent method, but unfortunately of very limited application

is to use a spectroscopic and visual binary whose orbit is on edge as seen from the earth. The elements of the visual orbit will give the semi-major axis in seconds of arc. The spectroscopic observations will yield the speed of approach and recession and the period, from which may be derived the circumference and radius. Knowing then the linear and angular value of the radius, the distance may easily be derived.

A somewhat similar process may be applied to moving clusters, that is clusters traveling through space like a swarm of bees. The proper motions of the members of the cluster will give the convergent point or direction of motion and also the angular cross velocity of each star. The spectroscope will give the radial velocity, which, combined with the direction of motion, will give the linear cross velocity. Again with the linear and angular values the distance may be computed.

Another method makes use of the Cepheid or pulsating variable stars. They show a marked correlation between their periods and their intrinsic brightness; the longer the period, the brighter the star. Remembering that light varies inversely as the square of the distance, given the real brightness and the apparent brightness, the distance may be computed. This, however, is not a wholly independent method. To get the zero point of the period-luminosity relation, trigonometric parallaxes of relatively near Cepheids must be used.

So called "dynamical parallaxes" may be derived from visual binaries. Kepler's third law, as corrected by Newton, gives a relation between the masses of the components of binaries, their periods and separation. To compute the masses the parallax or distance must be known. Conversely, if the masses can be inferred, the parallax can be computed. The foundations of this method also rest upon the trigonometric parallaxes, but by extrapolation its application can be extended to stars too far away to have a measurable trigonometric parallax. Professor Russell and Mrs. Sitterly have published more than 2,500 dynamical parallaxes and others have given shorter lists.

In 1914 Adams and Kohlschütter discovered that in the same spectral class the strength of some of the lines depends upon the luminosity of the star. From a study of these lines in the spectra of stars of known distance, and hence known absolute magnitude, they derived curves correlating the strength of the lines with the absolute magnitude and the distance. A single spectrum plate then may yield a parallax. Several thousand spectroscopic parallaxes have been published by the Mt. Wilson, Victoria, Harvard, Norman Lockyer, and other observatories. In the spectroscopic parallaxes it appears that the probable error of a single determination is about fifteen percent, whether the parallax is large or small. The probable error of a trigonometric parallax is about 0″.008 and is independent of the size of the parallax. For a parallax of 0″.05 these two would be about the same, so for parallaxes less than about 0″.05 the spectroscopic values are probably more reliable than the trigonometric, but for nearer stars the trigonometric is better.

The motion of our sun in space, 19 km a second, furnishes a base line that can be used to derive mean parallaxes of groups of stars, for example, stars of a given magnitude. This cannot be used for individual stars, because each one has a motion of its own and it is impossible to separate this from the displacement due to the change of position of our solar system, which is also progressive. If, however, it can be assumed that the individual motions are at random and in a large group will cancel out, then an average parallax for the group may be derived. It is found, for example, that the mean parallax for first magnitude stars is 0″.083, for seventh magnitude stars 0″.0082, that is the seventh are, on the average, ten times as far away as the first. Also that the mean parallaxes for tenth and eleventh magnitudes are 0″.0027 and 0″.0018, so when such stars are used as comparison stars in determining trigonometric parallaxes the correction from relative to absolute parallax is very small, only two or three thousandths of a second of arc.

Another statistical method involves star counts, the laws of stellar distribution, the luminosity function, and absorption by interstellar matter.

One of the more recent methods of measuring the distance of a star, due primarily to Professor Struve, is to make use of the lines in the star's spectrum that are due to interstellar matter; calcium, sodium, etc. Such lines can easily be identified because they do not shift position in proportion to the radial velocity of the star. If a star is near, its light will come through a comparatively small amount of interstellar matter and the corresponding spectral lines will be narrow and sharp; but the farther away the star the greater the amount of matter through which the light must pass and the stronger the lines. For stars of known distance, curves have been drawn correlating the strength of the interstellar lines with the distance, and, by extrapolation, the distance of other stars may be obtained. This would undoubtedly be a powerful method of measuring the distances of the more remote stars if it could be known that interstellar matter is distributed through space uniformly or in accordance with some known law.

So much for methods, now for some results: In 1838 three parallaxes were known, in 1880 about 20, in 1900 about 60, in 1915 about 200, in 1924 Schlesinger's first catalogue listed 1870, in 1935 Schlesinger's second catalogue listed 7534 trigonometric and spectroscopic and 2488 dynamic parallaxes, and the next ten year catalogue will probably show a corresponding increase.

The largest parallax is 0″.765 for a tenth magnitude companion to Alpha Centauri, only 4.3 light years away. There are about twenty-five stars with parallaxes greater than 0″.25, corresponding to a distance of thirteen light years. This list includes Sirius, magnitude —1.6, and also stars as faint as the 12th magnitude, whereas some of the brightest stars, as for example, Canopus, Rigel, Antares, and Deneb have parallaxes less than 0″.01.

Interesting as the parallaxes of individual stars are, they are even more important in connection with problems, the solution of which depends upon a knowledge of the parallax. Here are some such problems:

First, of course, the distance in any of the various units.

Again from the proper motion and parallax the cross velocity may be computed, that is the linear value of that component of the star's motion which is perpendicular to our line of sight to the star.

From the cross velocity and the radial velocity the motion of the star in space may be determined. From the apparent magnitude and parallax, the absolute magnitude may be derived. This is the brightness a star would have if it were at a standard distance, arbitrarily fixed at 10 parsecs. From tables of such absolute magnitudes combined with spectral classification the giant and dwarf characteristics of stars were discovered.

Another application is to the determination of the luminosities of the stars as compared to the sun, and to the fixing of the zero point of the period-luminosity curve.

Knowing the parallax, proper motion, and radial velocity, is it possible to compute the past and future positions, motion, and apparent magnitude of a star.

A knowledge of the parallax is essential to the determination of a linear scale for visual binary orbits; and from such binaries the masses of the component stars may be derived. Then if the angular diameter can be found by the interferometer or otherwise, the density may be deduced.

As mentioned before, parallaxes are needed for constructing the correlation curves for spectroscopic parallaxes, period-luminosity, mass-luminosity, interstellar lines, etc., and through the use of some of these, for finding the distances of clusters, nebulae, and galaxies. Finally, and all inclusive, a knowledge of the size, shape, motion, and general structure of the sidereal universe depends very largely either directly or indirectly upon the measurement of the distances of individual stars, fundamentally by the method of trigonometric parallaxes.

Meteoritic Fossils

By BEN HUR WILSON

One of the many questions which have doubtless perplexed the mind of every thoughtful student of "meteoritics" is the apparent absence of their remains in the sedimentary rock systems of the earth. Why have no fossil meteorites, so to speak, ever been found in the rocks? This is a legitimate question which demands more attention than it has received.

If the planetesimal theory, it is argued, be correct, then the rate of meteoric ingathering should have increased progressively as we pass

from the present back towards the beginning of the earth—a fact which should in turn imply that some meteorites certainly might be expected to have been preserved in the older stratified rocks.

Conversely, on approaching the Pleistocene and the present era, the infall has been greatly diminished, being now comparatively small. This is due to the fact, that, in theory at least, as time has progressed, more and more of the extraneous substance of the solar system, especially near the planetary orbits, is continually being swept out of space, thus materially reducing the rate of growth or accretion of the planet's mass, to a point where it is now considered to be almost negligible.

The writer does not remember of ever having seen verified any instance of meteoric material having been found in sedimentary rocks, under such circumstances as might indicate its being of the same age as the rocks themselves. La Paz, we believe, has reported finding meteoritic material imbedded in surficial calcareous deposits in the region of the "Odessa Crater" in Texas, under conditions, however, which indicate that these are only intrusions of considerable age, and certainly not contemporary with their original deposition, unless such deposits are in the nature of a tuffa or travertine of comparatively recent origin.

Many of our early geologists paused to consider the various aspects of this problem and Sir Charles Lyell, writing in 1855, in his "Manual of Elementary Geology" says, "We ought not, I think, to feel surprised that we have not hitherto succeeded in detecting the signs of such aerolites (meteorites) in the older rocks, for besides their rarity in our own days, those which fell into the sea (and it is with marine strata that geologists have usually to deal), being chiefly composed of native iron, would rapidly enter into new chemical combinations, the water and mud being charged with chloride of sodium and other salts.

"We find that anchors, cannon, and other cast-iron implements which have been buried for a few hundred years off our English coast have decomposed in part or entirely, turning the sand and gravel which enclosed them into conglomerate, cemented together by oxide of iron. In like manner meteoric iron, although its rusting would be somewhat retarded by its alloy with nickel, could scarcely ever fail to decompose in the course of thousands of years, becoming oxide, sulphuret, or carbonate of iron, and its origin being then no longer distinguishable."

"The greater the antiquity of rocks,—the oftener they have been heated and cooled, permeated by gases or by the waters of the sea, the atmosphere or mineral springs,—the smaller must be the chance of meeting with a mass of native iron unaltered." This is certainly valid reasoning, on the part of Lyell, and is the explanation which, to this day, is usually assigned for the apparent absence of all traces of meteoritic material from the older sedimentary rocks; and, one which we trust, will satisfy the curiosity of the younger students upon this especially fascinating phase of study and research.

It will be of further interest to learn, however, that Erman, does, in

his *Archives of Russia* for 1841 (p. 314) cite a very circumstantial account drawn up by a Russian miner of the finding of a mass of meteoritic iron in the auriferous alluvium of the Altai, which is certainly worth recording.

"Some small fragments of native iron were first met with in the gold-washings of Petropawlowsker in the Mrassker Circle; but though they attracted attention, it was supposed that they must have been broken off from the tools of the workmen. At length, at the depth of 31 feet 5 inches from the surface, they dug out a piece of iron weighing 17½ pounds, of a steel-gray color, somewhat harder than ordinary iron, and, on analyzing it found it to consist of native iron, with a small proportion of nickel, as usual in meteoric stones. It was buried in the bottom of the deposit where gravel rested on a flaggy limestone. Much brown iron ore, as well as gold, occurs in the same gravel, which appears to be part of that extensive auriferous formation in which the bones of the mammoth, the Rhinoceros tichorhinus, and other extinct quadrupeds abound. No sufficient data are supplied to enable us to determine whether it be of Post-Pleiocene or Newer Pleiocene date."

When considering the Altai iron, we have yet to speak of the possibility of its having penetrated to this great depth, through the drift material, by reason of the acquired momentum of its fall. Judging from experience gained in observed falls, this, however, would appear to be quite out of the question. In the case of the "Estherville Meteorite" which penetrated to a depth of 16½ feet, probably one of the deepest penetrations on record, we have an iron weighing somewhat over four hundred pounds, falling on soft ground in the edge of a swamp, while the Altai weighing only 17½ pounds was discovered at approximately twice this depth, in material certainly no less penetrable than that at the Estherville location.

Lyell said, "The preservation of the ancient meteorite of the Altai, and the presence of nickel in these curious bodies, renders the recognition of them in deposits of remote periods less hopeless than we might have anticipated." Perhaps, someone may even yet be able to report the discovery of undisputable meteoritic materials in older rock structure of the earth.

Finds such as this in the drift must, indeed, be very rare, for with the vast amount of strip mining, quarry stripping, and steam-shovel excavating now going on in this country for highway and other construction purposes, it would appear that someone would long before this have turned up at least one meteorite whose fall had occurred during or prior to the Pleistocene age, were such phenomena at all common.

In view of the above, it would be well for every research worker in "meteoritics" to make an attempt to interest all the power-shovel operators, with whom he comes in contact, in this subject, so that they would be constantly on the alert in their efforts to discover material of this type, in order that it might be preserved for sciene. Since many reports of the

discovery of native (drift) copper in masses of various sizes are constantly being made from many sections of the glaciated areas, it is not unlikely that reports of meteoritic iron would also have come in should any have been discovered and recognized as such.

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The Motion of the Heavenly Bodies; Its International Significance

By W. CARL RUFUS

The solution of the problem of the motion of the heavenly bodies has been achieved by the combined activity of many observers, computers, mathematicians, and astronomers, from the dawn of civilization to the twentieth century.

Early races including especially Chaldean, Egyptian, Indian, and Chinese, recorded observations of the stars and planets which they made chiefly for astrological use. The ancients determined with fair accuracy the times of recurrence of astronomical phenomena, such as the periods of the planets and the length of the month and the year. The Chaldeans have been credited with the discovery of the Saros, a period of 19 eclipse years containing about 6585⅓ days, which according to tradition was used also by the ancient Chinese for the prediction of eclipses. The Babylonians improved the system of celestial measurements based on the sexagesimal system which is still used in time and circular measure. The Egyptians acquired some astronomical knowledge and added their system of earth measurement or geometry as a method of attacking the problem.

The Greeks inherited the astronomical knowledge and observational records of their predecessors but in general they rejected the occultism of magic, divination, and astrological formulas. They loved knowledge for its own sake, freed the intellect, developed the reason, and trusted its conclusions. They learned that nature works by definite laws, which constitutes the beginning of natural science.

Plato is said to have set the problem to reduce the motions of the heavenly bodies to mathematical law. Eudoxus placed the earth at the center and, adopting a system of concentric spheres with uniform circular motions, compared his theory with observational data some of which he obtained at his own observatory, the first use of this method in scientific astronomy. This method gave the approximate direction of the planets but failed completely to account for the change in distance. Aristotle favored this system and conceived the spheres to have material existence and to be in mutual contact for the propagation of motion from the outermost, which was actuated by the Unmoved Mover.

Another geocentric solution was based on the geometrical system of

Apollonius of Perga, who drew a circle, known as the deferent, about the earth. On its circumference was the center of a second circle sometimes referred to as a sphere. The planet moved uniformly on the sphere, the center of which moved uniformly on the deferent. The combination of these motions gave a solution which included not only the approximate direction but also a varying distance. Additional circles were added as necessary to take care of new data, until the system became quite complex. As a slight simplification an eccentric circle was substituted for the deferent and the first epicycle. In this case, *e.g.*, when applied to the motion of the sun, the center of the circle was moved from the earth on a line toward the sun a distance just equal to the radius of the epicycle, a device which was adopted by Hipparchus, greatest of the Greek astronomers. This geocentric system was accepted by Ptolemy whose great work, the Syntaxis, described the system including one significant modification, the equant, which is an imaginary eccentric point from which the apparent motion seems to be uniform.

Some of the Greeks had vague ideas that the earth was in motion. Philolaus, a Pythagorean, imagined a central fire around which revolved the sun and the planets, including the earth. Their speed depended on their distances and they produced corresponding musical tones, "the harmony of the spheres." Hicetas and Ecphantos (real or fictitious) advocated the stationary heavens and a turning earth. Some speculations involved a limited heliocentric theory. Heraclides of Pontos advocated the rotation of the earth, also the revolution of Venus and Mercury around the sun, as it moved about the earth. It may be that his speculations went farther and anticipated the idea later advocated by Tycho Brahe that the outer planets also revolve about the moving sun. Aristarchus of Samos clearly advocated the heliocentric system, in which the earth and other planets revolve about the sun. Seleucos, a Babylonian, also affirmed the heliocentric theory. This system was rejected, however, in favor of the idea of a stationary earth advocated by Aristotle and by Ptolemy.

During the stationary period (c 400-1400) in Europe, altho the Syntaxis (or Almagest) found its way eastward, little advance was made by the Arabs or others regarding the motion of the heavenly bodies. In the thirteenth century the noted group brought together by Alfonso X, grounded in the methods adopted by the Arabs, computed their famous tables on the basis of the Ptolemaic system. In their astronomical encyclopedia the orbit of Mercury is represented by an elliptical diagram, a sort of anomalous idea, as the epicyclic system was yet followed.

In general during this period science was a confused medley of astrology, alchemy, magic, and theosophy. In the thirteenth century only one branch of study, astronomy, possessed the essentials of a complete science,—including methods of measurement for observational data, provisional hypotheses to test, laws to apply for the reduction of data, and comparison of results with the original theory. As a pioneer

science, astronomy deserves much credit in sorting the true from the false and in establishing a firm foundation on which to build modern science.

The authority of Aristotle was a chief factor in the acceptance of the geocentric system for nearly 2000 years. The work of Aristarchus was practically forgotten or at least neglected. Occasionally the Ptolemaic system was criticized and evident dissatisfaction spread in the fifteenth century. It remained for Copernicus (1473-1543) to advocate the heliocentric theory and to present to the world in written form his *De Revolutionibus Orbium Celestium,* which transfers the center of motion in the solar system from the earth to the sun. By the daily rotation of the earth on its axis he explained the apparent diurnal motion of the celestial sphere. The yearly revolution of the earth around the sun explained the apparent annual motion of the sun along the ecliptic through the zodiacal constellations. This annual motion of the earth combined with the revolution of the other planets around the sun explained the loops in the apparent paths of the planets among the stars. Altho Copernicus retained the epicycles of the Greek method his work provided a basis for advance toward the solution of the problem of motion of the heavenly bodies.

More accurate and more systematic observations were necessary to solve the problem; erroneous assumptions, for example, the metaphysical condition of uniform circular motions, had to be cast aside, erroneous laws of motion had to be replaced by the fundamental laws of dynamics, new methods of analysis had to be devised, and improved methods of computation to reduce and to apply the data. These were supplied during the inductive period beginning with Copernicus and culminating in the work of Sir Isaac Newton.

Tycho Brahe (1546-1601) rejected the heliocentric doctrine of Copernicus and adopted an ingenious compromise, which "saved the phenomena" and avoided the controversy regarding a moving earth. Around the motionless earth daily rotated the celestial sphere and annually revolved the sun, while the other planets, Mercury, Venus, Mars, Jupiter, and Saturn, all revolved about the moving sun. Tycho Brahe, however, made a great contribution to the problem of motion, by constructing larger and more nearly accurate instruments and by making more nearly accurate and more systematic series of observations. The data accumulated during a quarter of a century provided one of the prerequisites previously indicated.

In astronomy Galileo (1564-1642) is famous chiefly for his application of the telescope and resulting discoveries,—satellites of Jupiter, spots on the sun, mountains on the moon, and phases of Venus,—also for his acceptance of the Copernican system, ecclesiastical trial for heresy and subsequent verbal recantation to save his life. Later use of the telescope provided more nearly accurate data, but Galileo made another important contribution. He overthrew erroneous ideas regarding motion

and established some fundamental principles of dynamics, essential for the solution of our problem. The incident at the leaning tower of Pisa, perhaps apocryphal, illustrates his method. He dared to challenge the authority of Aristotle, who taught that bodies fall according to their weight.* In the presence of faculty, students, and townsmen, he dropped balls of different weight which fell side by side. Thus he appealed to nature as the arbiter of natural law and the baneful influence of authority was overthrown. By experiment he established true laws of motion to replace the false.

Kepler (1571-1630) also broke the shackles of tradition by freeing the problem from the metaphysical condition imposed by the Greeks,—combinations of uniform circular motions. Using the improved data of Tycho Brahe, he formulated his three laws of planetary motion.

1. The orbit of a planet is an ellipse with the sun at a focus.
2. The radius vector (a line from the sun to the planet) sweeps over equal areas in equal times.
3. The harmonic law. The squares of the periods of revolution of any two planets are proportional to the cubes of their mean distances from the sun.

These laws were purely empirical. Why, the ellipse? It satisfied Tycho's data. Why, the constant areal velocity? Why, the harmonic law? These satisfied the data, they "saved the phenomena."

Newton (1643-1727) was born the year following the death of Galileo. He is quoted as saying: "If I have seen farther than others, it is because I have stood on the shoulders of giants." He builded on the work of Copernicus, Tycho Brahe, Galileo, and Kepler. Newton formulated the law of gravitation,—*Every particle of matter in the universe attracts every other particle with a force which varies directly as the product of their masses and inversely as the square of the distance between them.* This law constituted the first great physical synthesis, the greatest scientific generalization of the human mind to that time. Kepler's laws were formal, relating observations in space and time. Newton's law is physical, introducing new concepts, mass for example, which explains Aristotle's error and corrects Kepler's harmonic law. Newton rationalized Kepler's empirical laws and gave an analytical solution of the problem of motion of the heavenly bodies.

The end of the inductive period was followed by new instruments and methods of observation for improved data to test the law of gravitation and by new and improved methods of mathematical analysis to trace the effect of this law in a wide field of application, involving tides, form of the earth, perturbations, double stars, theory of the moon, motion of the perihelia of planets, etc. Newton's generalization was accepted as a final solution of the problem of motion of the heavenly bodies. Leibnitz hailed Newton, not only as the greatest genius because he had explained the universe, but also as the most fortunate, because there is only one universe to explain.

*Philoponos of Alexandria in the 6th century denied the doctrine and referred to experiment but his work remained unnoticed.

An unsolved problem was found, however, by Leverrier (1811-1877) who noted a discrepancy between the observed and computed position of the perihelion of Mercury's orbit. The change in the direction (the longitude) of this point may be computed on the basis of Newtonian gravitation, but the observed change eastward, 574 seconds per century, is about 40 seconds per century greater than the computed. Leverrier postulated an undiscovered intra-Mercurial planet to account for the excess and named it Vulcan. His successful part in the discovery of Neptune by mathematical analysis based on Newtonian gravitation gave added zest to the search for Vulcan. Lescarbault announced the discovery of Vulcan in 1859. Watson, second director of the Observatory of the University of Michigan at Ann Arbor, at a total solar eclipse in 1878 "discovered" two intra-Mercurial planets. Photographic methods subsequently disproved the existence of Vulcan.

Other proposed causes,—such as meteoric matter within Mercury's orbit, an oblate form of the sun, a slight modification of the inverse square in the law of gravitation,—lack confirming evidence, so the problem of the excess remained unsolved at the beginning of the twentieth century, and constituted an appendix or a new chapter in the solution of the problem of motion of the heavenly bodies.

Einstein (1879-) recently developed a new law of gravitation in his theory of relativity. It includes Newtonian gravitation which applies to material masses in the older sense, and also includes electromagnetic phenomena (*e.g.*, light rays) in a broader generalization. According to this theory, mass in motion is greater than mass at rest, mass is convertible into energy and light rays possess an element of mass or they are, at least, affected by gravitation.

Quantitatively there is a very slight difference between Einstein's law of gravitation and Newton's when they are applied to planetary motions. The broader generalization by Einstein includes Newtonian law in its terms of the first order and small higher order terms negligible in most cases. The supplementary terms, however, are sufficient to account for the excess in the motion of the perihelion of Mercury's orbit. Two other tests proposed by Einstein, not directly related to our subject, also appear to have been satisfactorily met.

Now, let us make the application implied in our subtitle, *Its International Significance*. The chief contributors to the problem of the motion of the heavenly bodies set by Plato, a Greek, represent many countries: Copernicus, a Pole; Tycho Brahe, a Dane; Galileo, an Italian; Kepler, a German; and Newton, an Englishman. When we conclude with Einstein, we find a climax to our subject. A Jew by race, international by training and experience, Einstein left Berlin and is now a citizen of the United States of America. This one scientific problem has been solved by the contributions of famous representatives of many of the foremost nations and races of mankind.

ANN ARBOR, MICHIGAN, AUGUST 14, 1941.

The Eighth Sphere of Copernicus

By GRANT McCOLLEY

Some years ago the writer protested briefly against the growing belief that Copernicus regarded the sphere of the fixed stars as a shell, and that he located the stars upon the surface of this rigid shell.[1] So widely accepted has the belief become, that amplification of this protest is essential. Sir William Dampier-Whetham writes in his frequently reprinted "History of Science" that Copernicus "still accepted the ancient view that the stars were fixed to a sphere at a constant distance from the earth [*sic*]."[2] Describing the work of Giordano Bruno, A. Wolf states that Nolanus "went further than his master [Copernicus], and abandoned the belief that the stars are fixed to a crystal sphere having the sun at its centre."[3] Among other contemporary writers who advance this interpretation, the most recent is Dr. Edward Rosen, who declares that Copernicus "regarded the universe as a huge sphere; imbedded in its surface were the fixed stars, all at equal distances from the center of the universe."[4]

Without exception, these unqualified assertions are not supported by primary documentation. In the case of the writer last cited, a request for such documentation still remains unanswered. The fact is, Copernicus made in "The Revolutions" no statement which could be used to support the belief. The one possible item of evidence is the diagram of the universe presented in the first book of "The Revolutions." Here, the region of the fixed stars is indicated by a circle which encloses the orbit of Saturn. Above this circumscribing circle is the legend: *Stellarum fixarum sphaera immobilis.*

When broken down for analysis, the statement of Dampier-Whetham and others of this school consists of two assumptions. The first, and perhaps basic assumption is that the Ptolemaists and related astronomers attached the stars to a crystal sphere; the second, that Copernicus followed astronomers who did this. In keeping with the second, the first assumption of the argument is set forth without any supporting evidence.

During and preceding the century of Copernicus, the ruling astronomy was a revised Ptolemaic, particularly as expounded in the many commentaries on the *Sphere* of Sacrobosco (John of Holywood). Some few believers in Aristotelian cosmology perhaps remained, but, as J. L. E. Dreyer has noted, this cosmology, as a cosmology, went down before the Ptolemaic during the thirteenth century.[5] Without any exception that I have observed, the commentators on the *Sphere* who discussed the eighth orb uniformly described it as an extended zone, and not as a shell. Following Alphraganus, Christopher Clavius gave the depth of this extended zone as $22{,}612\frac{1}{2}$ semidiameters of the earth.[6] The spherical outside limit of the zone was termed the convexity; the

inner limit, the concavity. The distance from the inner concavity to the central earth again was 22,612½ semidiameters of our globe. Stated differently the distance from the earth to the inner concavity of the sphere, and the distance from the concavity to the outer convexity were precisely the same. In each case it equalled one-half the radius ascribed to the mundane universe.

The use of a relatively extended zone for the fixed stars carries with it the implication that the Ptolemaists regarded the zone as a region which *contained* the fixed stars. Because of a general acceptance of the dogma that nature permitted no vacant space in the universe, use of the zone indicates that the stars were regarded as scattered thruout it, and not as located upon either concavity or convexity. Indeed, if the Ptolemaists located the stars upon either convexity or concavity or attached them to a crystal sphere at equal distances from the earth, they had no need to postulate an extended zone for the "sphere" of the fixed stars.

The unsupported assumption that the Ptolemaists regarded the fixed stars as attached to a crystal shell also ignores the conventional description of both the sphere and the fixed stars. In the representative account of Clavius, the sphere of the fixed stars was so termed because it carries, whirls about, and *contains* all the fixed stars (*"At vero sphaeram stellarum fixarum nominat, quia defert, circumvehit, & continet omnes stellas fixas"*). The stars are called fixed, Clavius continued, because they always retain among themselves the same relative situation, order, and distance (*"Sed ideo appellantur fixae, quod semper eundem inter se situm, ordinem, atque distantiam servent"*).[7] This belief, Clavius noted, was held by Ptolemy, Albategnius, Regiomontanus, and others. The statement was not uncommon that each of the stars kept one distance from the earth, but the Ptolemaists did not say that all stars were equidistant from the earth.[8]

There was, in addition, nothing heterodox in the belief that the stars are located at varying distances from the earth. Saint Augustine, whose *Commentary on Genesis* was available throughout the Middle Ages, and whose personal authority was unsurpassed during this period, declared that some stars are more distant from the earth than are others.[9] This conclusion he based in part upon the difference in brilliance found among the stars. In reviewing the cosmological beliefs of various Church Fathers, Thomas Campanella wrote in 1615 that "because of the authority of Chrysostom's interpretation, Saint Thomas [Aquinas] was moved in the *Summa Theologica*, I, 70, 1, to agree more with Ptolemy than with Aristotle, and says with the Pythagoreans that the stars are not fixed as knots in a board."[10]

Among Christian astronomers of the sixteenth and preceding centuries, it generally was accepted that the stars of heaven are "innumerable." As in the case of Saint Augustine, the primary basis of this belief was Scripture, particularly Genesis.[11] Clavius, major author of the Gregorian Calendar, and unquestionably able as an astronomer and

mathematician, suggested that there could be 10,000 stars in each of the forty-eight constellations, or a total of 480,000.[12] The question, *"Quot sunt fixae stellae?"* Thomas Blebelio answered with the statement: *"Etsi innumerables sunt stellae; veteres tamen ex his 1022 notarunt, easque in 48 imagines distinxerunt."*[13] Belief in the existence of a half-million and more unnumbered and unseen stars is not compatible with belief in a crystal sphere to which all the stars are attached.

As this brief review has attempted to show, there is no justification for the assumption that during and preceding the century of Copernicus, responsible astronomers regarded the eighth sphere as a crystal shell to which the fixed stars are fastened. Equally unfounded is the second assumption—the idea that Copernicus advanced or held such a notion. The one item of evidence which might be interpreted to support this assumption is that mentioned above: the diagram which placed above the outermost circle, the legend *"Stellarum fixarum sphaera immobilis."*[14]

This diagram of the Copernican system places the sun in the center. Beyond and enclosing the sun lie nine major circles, together with the epicycle of the moon. The outermost major circle, numbered I, carries above it the legend quoted; the next, numbered II, *"Saturnas anno: xxx revolvitur;"* the third, *"Iovis xii annorum revolutio,"* and the last, numbered VIII, *"Mercurii lxxx dierum."* The fifth and seventh circles, unnumbered, mark the zone in which moves the epicycle of the moon. Since eight of the nine circles obviously are geometrical representations—six of them planetary orbits—we have no justification for assuming that the last is a crystal sphere.

Equally important is the fact that the diagram used in "The Revolutions" is precisely that previously employed by Rheticus in "Narratio Prima."[15] Since Rheticus supervised the printing of the early books of "The Revolutions," it is logical to assume that it was he who caused the use of his diagram in the work of Copernicus. In any event, since the diagram is that employed first by Rheticus, his statements are important to its proper interpretation.

In "Narratio Prima," Rheticus said nothing of fixed stars attached to a crystal sphere. He did, however, mention several times the inner concavity of the eighth sphere. By so doing, he inplicitly accepted and used the idea that the eighth sphere is an extended space which began with or beyond the orbit of Saturn. He also stated that the "hypotheses" of Copernicus stopped at the orb of the stars, *i.e.*, at the inner concavity which marked the beginning of the sphere of the fixed stars.[16] We may add that three decades after publication of "The Revolutions," Thomas Digges included the internal concavity of the eighth sphere in his diagram of the Copernican system.[17] In the second decade of the seventeenth century, Kepler's *Epitome* of Copernican astronomy illustrated the system by a diagram which showed the inner concavity of the eighth sphere.[18] Again in keeping with that of Digges, Kepler's diagram depicted the fixed stars as dispersed throughout unbounded space.

If a circumscribing circle must represent a crystal sphere to which the stars are attached, then both Digges and Kepler employed a universe both enclosed and unbounded at one and the same time. This of course is nonsense. To Digges and Kepler, and to Rheticus, the circle which circumscribed the planetary orbits represented the inner concavity traditionally ascribed to the eighth sphere. To the Ptolemaist, accustomed as he was to think of the eighth sphere as a zone limited externally by the convexity, and internally by the concavity immediately beyond the orbit of Saturn, the single circle shown on Rheticus' diagram would represent the inner concavity. I may add that there has not been cited any astronomer of the sixteenth or seventeenth centuries who stated or definitely implied that the single circle of the Rheticus (or Copernican) diagram represented a shell to which the fixed stars are attached.

The most authoritative evidence naturally consists of the statements made by Copernicus himself. In "The Revolutions," I, viii he wrote that "they" say there cannot be physical body, nor place, nor emptiness beyond heaven, and that nothing can go out of heaven. Truly, he observed, it is a marvel, if something may be restrained by nothing. But if heaven is infinite, and only the internal concavity finite, so that all things (*unumquodque*) will be contained in it regardless of the magnitude which they occupy, much more perhaps could it be proved that nothing lies beyond heaven; but heaven [being unbounded or infinite] will remain immobile. The greatest argument by which they labor to affirm that the world is finite is that it moves. It being certain that in its rotation, the spherical earth remains bounded by a confining surface [and does not disintegrate], we therefore may give over the question of whether the universe may be finite or infinite to the disputations of natural philosophers. Why then, Copernicus inquired, have we hesitated to grant to the earth the mobility in keeping with its [spherical] form, all for the reason that the world, whose end is unknown and cannot be known, may fall down? In Book I, x, Copernicus opened description of the order and situation of the planets by stating that "First and above all is the sphere of the fixed stars, containing itself and all things, and for this reason immobile."

It is first of all apparent that to Copernicus, as to the Ptolemaist, heaven or the eighth sphere is a space which contains bodies. It is equally obvious that he did not regard this sphere as a crystal shell, or as a surface to which stars are attached. Of the Ptolemaic eighth sphere, he discussed and accepted only the internal concavity, and remarked of the world that its end or limit is unknown and cannot be known (*"mundus, cuius finis ignoratur scirique nequit"*). The diagram by Rheticus, first set forth in "Narratio Prima" and later reprinted in "The Revolutions," shows only the internal concavity. "Narratio Prima," we recall, was composed while Rheticus was in personal communication with Copernicus.

It would not be uninteresting to inquire by what steps historians have

reached the belief that Copernicus regarded the eighth sphere as a crystal shell to which all stars are attached. However, we may note that the belief did not arise from knowledge of the dominant Ptolemaic astronomy, nor from attentive reading of either Copernicus or competent contemporary interpreters of "The Revolutions." Under such conditions it is both unfortunate and unscholarly to fasten the long-rejected and pre-Ptolemaic idea of a star-gemmed crystal shell upon the astronomer who declared the end of the world is not known and cannot be known.

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[1] *Cf.* "Nicholas Copernicus and an Infinite Universe," *Popular Astronomy*, XLIV (1936), 525.

[2] *A History of Science*, Cambridge, 1940 (1929, 1930, 1931, 1932, 1935, 1936, 1938), p. 122.

[3] *A History of Science, Technology, and Philosophy in the Sixteenth and Seventeenth Centuries*, London, 1935, p. 25.

[4] *Three Copernican Treatises* (Columbia University Records of Civilization), New York, 1939, p. 39.

[5] "*Mediaeval Astronomy*," in Charles Singer (ed.), *Studies in the History and Method of Science*, Oxford, 1921, pp. 110 ff.

[6] *In Sphaeram Ioannis de Sacrobosco Commentarius*, Rome, 1585, p. 215. Jacques Lefèvre, *In Astronomicum Ioannis de Sacrobosco*, Paris, 1507, I, ix, gave the depth of the eighth sphere as 20,110 semidiameters of the earth. He computed this distance as 65,357,500 miles. An extended list of pertinent fifteenth and sixteenth century astronomical commentaries may be found in the writer's, "The Astronomy of *Paradise Lost*," *Studies in Philology*, XXXIV (1937), 223, n. 53, and 227, n. 71.

[7] *Op. cit.*, p. 21.

[8] *Cf.* Sebastian Theodoric, *Quaestiones Sphaerae*, Wittenberg, 1567, p. 71.

[9] *De Genesi ad Litteram Libri Duodecim*, II, xvi. In discussing the question, "*An sidera aequaliter fulgeant?*" Saint Augustine wrote of the stars: "*longius positas parvas videri.*"

[10] *Apologia pro Galileo*, Frankfort, 1622, p. 43.

[11] *City of God*, XVI, xxiii.

[12] *Op. cit.*, pp. 149-150.

[13] *De Sphaera, et primis Astronomiae rudimentis Libellus*, Wittenberg, 1595, p. 7.

[14] *De Revolutionibus*, Thorn, 1873, p. 29.

[15] *De Libris Revolutionum ad Ioannem Schonerum Narratio Prima*, Thorn, 1873, p. 465.

[16] *Ibid.*, pp. 466 ff.

[17] *A Perfit Description of the Caelestiall Orbes . . .* An appendix to Leonard Digges, *Prognostication Euerlastinge*, London, 1576, fol. 43.

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Meteors Photographed with the 18-Inch Schmidt Camera on Mount Palomar

By FLETCHER WATSON

In the study of meteor frequency the impersonal photographic emulsion is proving increasingly useful. Hitherto the published rates and analyses have been based on meteors recorded by short-focus lenses, but the wide angle of observation and the resulting optical imperfections over the field have been a possible source of error. Consequently the meteor rate recorded by fast Schmidt cameras, whose fields are almost optically perfect, should place our statistics upon a more satisfactory basis.

Through the kindness of Dr. Fritz Zwicky I recently had the opportunity of searching for meteor trails upon films obtained with the $f/2$ 18-inch Schmidt camera located on Mount Palomar. The films available were those taken for the super-nova patrol. Of the many different types of emulsion used only three groups of the faster were examined—Agfa Super Pan Press; Eastman 103-0; and a mixture of Agfa Supersensitive Panchromatic, Eastman Supersensitive Panchromatic, Eastman Superpanchro Press, and a few Eastman Panchropress.

Each of the films was placed on a well-illuminated ground glass frame and viewed through a large reading glass magnifying about two times. Questionable meteors, possibly scratches, were examined under magnification of fifteen power. During the search the faintest trails probably escaped notice; consequently the frequencies derived below represent the minimum performances of the camera-emulsion combinations.

On 394 films having a total exposure time of 10,663 minutes 81 meteor trails were found. Thus the average rate for these emulsions was one meteor per 132 minutes. Table I presents the results for the three groups of emulsion; the uncertainties of the frequencies are proportional to $N^{-1/2}$.

TABLE I

Emulsion	Agfa Super Pan Press	Eastman 103-0	Mixture
Total exposure	2032	3005	5356 minutes
N	22	26	33
Interval per meteor	105 ± 22	116 ± 23	162 ± 27 minutes

The emulsions considered fastest proved to be most effective in recording meteors. The several emulsions are, however, not strictly comparable for the Eastman emulsion of series O is sensitive only to blue light while all the others are panchromatic. Casual inspection, without record, of the other emulsions used in the super-nova search indicated, as we would expect, that they were less efficient in the photography of meteors.

Since the time available for the search was limited the whole file of films could not be examined. The number of meteors found is, however,

sufficient for general statistical treatment, if we forego treating the several emulsions separately. Table II includes the analysis for diurnal variation in meteor frequency. In general the trend of the frequency follows that previously derived[1] for meteors photographed through short-focus lenses.

TABLE II

Mid-exposure	$17^h\ 30^m$-$20^h\ 30^m$	$20^h\ 30^m$-$23^h\ 30^m$	$23^h\ 30^m$-$2^h\ 30^m$	$2^h\ 30^m$-$5^h\ 30^m$	L.M.T.
Total exposure	2871	3885	2904	1003	minutes
N	18	28	25	10	
Interval per meteor	160 ± 38	138 ± 26	116 ± 23	100 ± 32	minutes

Table III presents the analysis for annual variation. Here the well-known increased rate of meteor appearance during the later half of the year is well confirmed.

TABLE III

Months	J-F-M	A-M-J	J-A-S	O-N-D	
Total exposure	1890	1860	1950	4965	minutes
N	4	12	24	41	
Interval per meteor	472 ± 236	155 ± 45	82 ± 17	121 ± 19	minutes

Since the field of this camera is less than ten degrees and the exposures averaged only 27 minutes, we may separate the films into large groups according to their zenith distances at mid-exposure and investigate the influence of zenith distance upon observed frequency. From the results in Table IV we see that the chances of photographing a meteor are four times greater at zenith distances of 70° than at the zenith.

TABLE IV

Zenith distance	0-20°	20-40°	40-60°	60-80°	
Total exposure	942	3017	4284	2164	minutes
N	3	12	36	29	
Interval per meteor	314 ± 220	251 ± 69	119 ± 20	75 ± 14	minutes

Öpik[2] and La Paz[3] have independently shown that a telescope of field-diameter D has for meteors an effective field of area $\pi D^2/4 + LD$, where L is the average path length of the meteors. Recently this equation has been used in an attempt to determine the average path length of telescopic meteors from the observed frequency with which they have both, one, or neither end of their paths within the field of view.[4] This same theory can be applied to photographed meteors; Table V shows the numbers falling into the three categories and the ratio L/D indicated.

TABLE V

Category	Both ends	One end	Neither end within field
N	41	34	6
%	51	42	7
L/D	0.3	1.0	0.8

As was found for the telescopic meteors the several values of L/D disagree. Among the factors contributing to the disagreement, one of the greatest is probably the differences in distribution of light intensity

along the meteor paths—some meteors have strong flares near their terminal point.

The field of the camera is about 9° and we shall not make a gross error by assigning an average length of 5° to the meteors recorded. The effective field is then 110 square degrees, which, at a height of 90 kilometers in the zenith, includes 270 square kilometers. Inasmuch as the total atmosphere has an area of some 5.2×10^8 square kilometers, each meteor photographed represents two million others appearing elsewhere in the atmosphere. Near the zenith this camera records one meteor in approximately 300 minutes; in the course of a day the total number of meteors of equal magnitude appearing in the whole atmosphere is about ten million. Comparison with the frequencies found from visual observation[5] indicates that the faintest meteors recorded by this camera are between the second and third magnitudes. Unfortunately circumstances prevented simultaneous visual and photographic observations which would have placed this limiting magnitude more precisely.

It is a pleasure to express my thanks to Dr. Zwicky for his kindness in making available the films taken with the 18-inch Schmidt camera.

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Inter-American Astrophysical Conference

On invitation of President Manuel Avila Camacho of Mexico, a conference of leading American, Mexican, and South American astronomers met at Mexico City, Puebla, and Tonanzintla from February 16 to February 25.

Occasioned by the dedication of the new 27-31-inch Schmidt-type telescope, just installed at Mexico's National Astrophysical Observatory in Tonanzintla, the conference heard papers covering nearly the entire field of modern astronomy and geophysics.

The Mexican president, in his invitation to the participating scientists, stated that it is the purpose of the Government of Mexico to contribute, in the American continent, to the continued progress of culture and science, thus counteracting, as far as possible, the paralyzing of cultural and scientific activities in countries devastated by war.

The new Schmidt is strategically located in latitude 19° north, and is the most powerful telescope in the tropics. The optical work was by Perkin-Elmer Corporation, of Glenbrook, Connecticut, and the mounting was designed and constructed in the shops of the Harvard College

Observatory, under the direction of Dr. George Z. Dimitroff, superintendent of the Oak Ridge station. The instrument, in spite of labor shortage and priorities, was completed in the record time of six months, and was transported to Mexico by truck.

Dedication ceremonies on February 17 included addresses by President Camacho and Dr. Gonzalo Bautista, governor of the State of Puebla, in which Tonanzintla is located. Following the ceremony, Dr. Dimitroff described and demonstrated the equipment of the new observatory.

On the evening of the 17th, also at Puebla, a public meeting was held, at which Dr. V. M. Slipher, director of the Lowell Observatory, and Dr. Robert R. McMath, director of the McMath-Hulbert Observatory of the University of Michigan, were heard.

The Interstellar Medium was the subject of the first session, on Wednesday morning, February 18. Dr. Harlow Shapley, director of Harvard College Observatory, presided. Speakers were Dr. Walter S. Adams, Identification of Interstellar Lines and Bands; Prof. Joel Stebbins, Irregularities in Space Reddening; Dr. Christian T. Elvey, The Night Sky; and Dr. Fred L. Whipple, The Theory of the Interstellar Medium.

Papers for the afternoon session on *The Classification of Stellar Spectra* (Dr. Henry Norris Russell, director of the Princeton Observatory, presiding), included General Problems of Spectral Classification, by Dr. W. W. Morgan; Dr. Alexander N. Vyssotsky on The Classification of Faint Stars; Dr. Bart J. Bok on The Annie Jump Cannon Bureau of Spectral Classification and Galactic Analysis; Diffraction Gratings for Faint Spectra, by Dr. Robert W. Wood.

Dr. Otto Struve, director of the Yerkes and McDonald Observatories, gave the address of the evening, on The Cosmogonical Significance of Stellar Rotation.

With Dr. Adams presiding, the morning session of the 19th was devoted to Problems of the Galaxy. Seven papers were presented as follows:

Dr. Joaquin Gallo—Star Counts on the Plates of the Zonal Astrographic Catalogues

Dr. Carlos Graef and Professor Fernando Alva, both of the staff of the Tonanzintla Observatory—Application of the Seares Exposure-Radio Method of Obtaining the Colors of Faint Stars

Dr. Paris Pishmish Recillas—Photographic Standards in the Harvard C Regions

Dr. Robert H. Baker—Stellar Distribution in Aquila

Dr. Bart J. Bok—The Local System

Dr. J. A. Pearce, director of the Dominion Astrophysical Observatory at Victoria, and Canadian representative at the conference, The Motions of the Class B Stars

Dr. N. U. Mayall—The Velocities of Globular Clusters.

Variable Stars was the general subject for the Thursday afternoon session, with Dr. Struve presiding. Dr. Sergei Gaposchkin spoke on The Classification of Variables; Dr. Cecilia H. Payne-Gaposchkin dis-

cussed Novae and Related Stars; Prof. Felix Recillas spoke on The W Ursae Majoris Stars; and Miss Henrietta Swope concluded this session with a paper on Variable Stars and the Galactic Nucleus.

A showing of motion pictures on The Growth of Crystals, by Dr. Wood, comprised the Thursday evening session.

With Dr. Pearce presiding, Time and Change was the subject of the seven papers of the morning session on Friday, February 20. These were:

The Mathematical Concept of Time—Dr. George Birkhoff
The Present State of the Theory of Stellar Evolution—Dr. H. H. Russell
Changes in the Periods of Variable Stars—Capt. T. E. Sterne
Transformations in Geometry—Prof. Alberto Barajas
The Emission of Charged Particles from the Sun—Dr. Manuel S. Vallarta
Solar Prominences—Dr. R. R. McMath
The Variation of the Sun—Dr. Donald H. Menzel.

Following a week-end spent at Mexico City and a trip to Morelia, with academic ceremonies at the University of Morelia, the concluding day of scientific papers was Wednesday, February 25, with sessions held at Mexico City.

Cosmic Radiation was the subject of the morning meeting, with Dr. M. S. Vallarta presiding. Speakers were Dr. Carlos Graef, Mr. Jaime Lifshitz, H. U. Martinez, and Dr. Alfredo Baños, Jr.

In the afternoon, with Dr. Baños presiding, Geophysical Problems were discussed by Dr. J. Gallo, Dr. L. Don Leet, Dr. Robley D. Evans, and Dr. Ingenia Cleofas Gomez.

Dr. Shapley addressed the concluding session of the conference on Wednesday evening on the subject Time and Change in the Metagalaxy.

—L. C.

Following are abstracts of some of the papers given during the conference.

The Surfaces of the Major Planets

By V. M. Slipher

The Lowell Observatory for nearly half a century has been occupied with studies of the major planets of our solar system, and it is our intention on this occasion to speak concerning some of the more important observations and the conclusions reached regarding these neighbors of the Earth. Many of the observations have been through photographic means and lantern slide copies will be shown of various of these negatives, because in this manner the observational results can be advantageously presented. These lantern slides will illustrate seasonal changes on Mars, as seen in his polar caps and other of his surface features, the presence of clouds, and other atmospheric phenomena, as well as secular change in features of the Martian surface. Similar color-filter photographs of other of the planets, especially of Venus, Jupiter, and Saturn

will present certain of the important observations concerning their atmospheres and surfaces. Slides from spectrum plates will also be used to aid in revealing the power of such light analysis in informing us on the chemical composition of the planet atmospheres, and also in enabling us to measure the length of the planet's day.

Naturally in analysing and interpreting this various observational material we have been aided and guided: 1) by our direct knowledge of the Earth as a planet, 2) by the established and remarkable fact that the entire universe of stars and nebulae are built wholly and only of our Earth-like chemicals, and 3) by the fact that these bodies are all being disposed and controlled by the same physical laws as the material substance immediately about us.

Thus through prolonged and careful observation we have found clear evidence of a wide variety of world in temperature, atmosphere, and surface condition, among the nine major planets of our solar system. It is certain now that none is exactly like the earth, but that the one, Mars, we now know to most resemble it, is more like the Earth than was thought possible five decades ago, when Lowell Observatory began its work; and certain that the one, Venus, at that time believed much like the Earth, proves to be far less so than was expected. Then it is clear that of the Earth-sized planets, Mercury and Pluto are the least like our planet, owing mainly to their very unfavorable relation to the sun, the one too near and overheated, the other too far away and cold. And finally that group of the four giant planets, Jupiter, Saturn, Uranus, and Neptune have during this time yielded to study certain information that clearly shows their strong family likeness, their nature and condition of atmosphere and surface all of which shows them widely different from our planet and our nearest of kin.

Irregularities in Interstellar Absorption

By Joel Stebbins

With a new combination of photoelectric cell and several filters, it has been possible to measure the light of stars in six colors, ranging from 3500 A in the ultra-violet to 10,000 A in the infra-red. These spectral gradients supersede the measures of stars in two colors on which previous determination of selective absorption in space has been based. In the new system, using the ultra-violet and infra-red, the range in color index from spectral class O to late M is about 11 magnitudes. The scale is six times the previous photoelectric scale, but the dispersion in color for stars in the same spectral class is about 5 times the previous dispersion, so that the net gain is not so large as might be expected. There is the well-known difference between giant and dwarf stars, but within these classes there seems to be no dependence of color upon absolute magnitude.

When the new gradients of reddened B stars are reduced to a standard scale, it is found that the interstellar absorption is qualitatively the same

in different parts of the sky. The deviation from the law of the inverse wave-length is nearly the same for all stars tested. The evidence is still strong for a high ratio of total to selective absorption. While the obscuring properties of interstellar dust appear to be uniform, the distribution of this dust in our galaxy is very irregular, a fact which is also shown by star counts and even by appearances obvious to the naked eye. The present study confirms and extends earlier reports on obscured and clear regions among the star clouds of the Milky Way.

The work has been done at Mount Wilson and Washburn Observatories, and has been participated in by C. M. Huffer and A. E. Whitford.

Problems Relating to the Light of the Night Sky

By C. T. Elvey

A review of the photometric, polarimetric, and spectrographic investigations of the light of the night sky shows that the origins of the illumination may be assigned as follows:

A. In the Galaxy
   1. To the stars
   2. To the galactic light—interstellar dust clouds illuminated by stars

B. In the Solar System
   1. To the zodiacal light—meteoric particles illuminated by the sun

C. In the terrestrial atmosphere
   1. To the permanent aurora—radiations from atoms and molecules
   2. To scattered light from all the above sources.

The portion of the light of the night sky which we wish to discuss is the permanent aurora which has an emission spectrum composed of lines and bands. The atom of oxygen accounts for two of the strongest features of the spectrum—the green auroral line and a blend of two lines in the red region. The next strongest feature is the blended sodium D-lines. The major portion of the remainder of the spectrum is accounted for by the bands of the nitrogen molecule, the Vegard-Kaplan System dominating the violet region and the First Positive System the infra-red region. It is quite likely that the strongest feature in the ultra-violet belongs to a band system of the oxygen molecule.

The physical processes in the upper atmosphere are not well enough known to give a conclusive explanation of the excitation of the atoms and molecules. However, S. Chapman has offered a very plausible theory to account for the source of energy, namely that the sunlight is stored through the dissociation of oxygen molecules and that the energy is recovered by recombination.

There are many discrepancies between the observational material and Chapman's theory. However, since it appears to have a sound basis we are attempting at the McDonald Observatory to obtain additional observations which we hope will clarify the situation. We have made intensity measures from spectrograms of the strongest features in the visual part of the spectrum and have undertaken series of observations

with photoelectric photometers in the infra-red region. Our aims have been to determine the height in the atmosphere from which the radiations came, the diurnal variation, and the nature of the irregular variations.

On the assumption that the light of the night sky is uniformly distributed over large geographical areas it is possible to compute theoretical curves of the variations in intensity with the zenith distance and the height to the emitting layer. The observations, however, are difficult on account of the instrumental troubles which are encountered. Further, they are complicated because of the uncertainty of the extinction from the lower atmospheric layers. The spectrophotometric observations indicate a height of the order of that of the E-layer of the ionosphere. The photoelectric photometer has advantages over the spectrographic method and the preliminary determination of the variation with zenith distance places the emitting layer at a height of 125 km.

The diurnal variations of intensity determined from spectrographic observations show some interesting relationships. If the instrument is pointed to a zenith distance of 70° the diurnal curves for the green auroral line, the red oxygen lines, and the sodium lines are essentially symmetrical. On the other hand, if the spectrograph is pointed toward the western horizon at a zenith distance of 85° we find that the red lines of oxygen are greatly enhanced during twilight. They decrease rapidly at first and then more slowly, reaching a steady value after two or three hours which remains through the night. This appears to be a direct effect of the sun illuminating the upper atmosphere and it gives promise of an independent method of investigating the high levels of the earth's atmosphere.

The spectrographic method requires long exposures and consequently the resolving power on the time scale for the observations is poor. The photoelectric photometer has a great advantage in this respect since observations can be taken at short intervals, say every five minutes or less, instead of every hour or so.

An examination of the curves obtained with the photometer shows that the diurnal variation of intensity is rarely smooth but has many irregularities in it. Occasionally a comparatively smooth curve is found. I refer to such as a quiet night and it is almost certainly associated when the magnetic activity is small. The greater the irregularity of the light of the night sky, the greater is the magnetic activity. This has been amply illustrated by some recent work of D. N. Barber in which he shows a close correlation between the two phenomena.

A survey of the curves of diurnal variation of intensity indicates that there is a general background illumination of the night sky which in the infra-red portion of the spectrum gradually decreases through the night and superimposed on this are the irregular fluctuations. Simultaneous observations in different regions of the sky give the same background for the diurnal variation but the irregularities are not the same, thus showing a non-uniformity of the light of the night sky. Chapman's

theory may explain the background illumination of the night sky but there is not too much hope for it to explain the irregular variations.

A number of questions may be raised which will require further observational work. What is the nature of the irregular variations and of the non-uniform distribution of light over the sky—is it a result of patches of light which move? If so, in what direction do they move and with what speed? Also, how large are they and how are they related to the areas of increased ionization that are observed in the ionosphere? Since the fluctuations are larger and more frequent during times of increased magnetic activity, do they have the same relationship to magnetic latitude as does magnetic activity? One would also inquire whether the background luminosity of the night sky is a steady feature or is it affected in the same manner as the irregular variations?

Investigations are in progress at the McDonald Observatory to provide answers to some of the questions but only tentative results can be given. Two photometers each observing the region of the north pole but separated in distances up to 25 miles show, in general, identical results. If the illumination comes from a height of 100 km, approximately that of the E-layer, the non-uniformity of the light over the sky indicates differences in intensity between points separated by as little as 100 miles.

If the disturbances in the light of the night sky come from the E-layer then we might expect correlations of the variations in signal strength of a broadcast station with the variations in the intensity of the light of the night sky at a point from which the radio wave is reflected. Preliminary observations indicate that this phase of the problem will be productive.

Large Diffraction Gratings for Schmidt Telescopes

By R. W. Wood

In the past the method employed for the simultaneous photography of the spectra of large numbers of faint stars has been to place a glass prism over the object glass of the telescope with which the star group is photographed. The star images are thus drawn out into spectra which are permitted to drift slightly in a direction perpendicular to their length, thus giving narrow bands on which the absorption lines of the stars are as clearly visible as when photographed one at a time, with a small spectroscope. Spectra can also be obtained by passing light through a diffraction grating instead of through a prism, the grating being a glass plate on which parallel equi-distant lines have been ruled with a diamond point. The very complicated machine for ruling such gratings can rule from 500 to 30,000 lines in the space of an inch. Until recently these gratings have not been used for astronomical research except in the case of the sun where the great intensity of light compensates for loss due to the fact that the grating gives a number of spectra spread out end to end instead of a single one as yielded by the prism. It has been found, however, possible to construct transmission gratings

which throw as much as 90 percent of the light into a single spectrum. These have been made by ruling a grating on a flat plate of highly polished copper, with a diamond tool ground and polished to such a shape that its cuts a groove with one steep and one oblique side. This plate is then flowed with a solution of a transparent plastic which, when dry, is stripped from the plate and cemented to a glass plate, with the grooves uppermost. The grating lines are now in the form of long thin prisms, which reflect most of the light in the direction of *one* of the diffraction spectra, the others now being very weak or invisible.

Gratings of practically any size can now be made by mounting the grooved films side by side and one above the other on a large glass plate like the squares of a chess board. A mosaic grating of this type has been made on a glass disk 18 inches in diameter and tried out during the past summer at the Observatory on Mt. Palomar in California on the large Schmidt telescope in collaboration with Dr. F. Zwicky. The results obtained indicate that such gratings will probably give results that cannot be obtained with prisms owing to their higher dispersion in the red and infra-red regions of the spectrum. A technique of mounting the films, which measure 4 × 6 inches, with the lines exactly parallel, has been developed and plans are being made for the construction of these gratings for the larger Schmidt telescopes at Mt. Palomar and the Harvard Observatory.

Gratings of 800 and 1400 lines to the inch have proved most useful, as only very short spectra are needed for the classification of stars. Longer spectra would cause overlapping in the case of fields richly populated with stars.

Another type of grating has been devised for determining the individual velocities of a large number of stars simultaneously, which is now done with an objective prism, and a ray filter of neodymium chloride (the method developed by Pickering and Wood many years ago). An objective prism of small angle is cut in two along a line perpendicular to its refracting edge and each half covered with a diffraction grating which deviates the rays in a direction opposite to the deviation given by the prism and of the same amount. The length of the spectrum is increased by this process, since with the grating the red light is more deviated than the violet, while the opposite is true in the case of the prism. The half prisms are now mounted one above the other with the refracting edges to the right and left respectively, and by properly adjusting the angles, we obtain, when the objective of a telescope or Schmidt camera is covered by the bi-prism grating two spectra of each star, parallel to each other and lying side by side in the violet region, while the red regions of the two spectra lie to the right and left, respectively. If the star is moving toward the observer the spectra are pushed together in the direction of their length, while if the star is moving away they are drawn apart, the shift of the lines in the violet region with respect to each other being measured in the case of each

star. The method has been tried out at the Harvard Observatory, with a rather crude bi-prism grating constructed by the author, and has given results which look promising. The shift in this case is double that measured with respect to the neodymium absorption line, or with respect to the central image in the case of a grating since we have two spectra moving in opposite directions.

Novae and Related Stars

By Cecilia Payne-Gaposchkin

Introductory.—There are effectively three types of novae: supernovae, novae, and U Geminorum stars. Three essential problems will be considered: the *what*, the *how*, and the *why* of the nova process.

Nature of the Nova process.—Novae and supernovae undoubtedly present a release of energy, resulting in a stellar explosion. For novae the process is superficial and the consequences trivial. For supernovae the energy released is comparable with the total energy of the star. For U Geminorum stars the energy released is negligible compared to the star's energy; here also the sudden brightening is caused by an expansion, but there seems to be no explosion.

Details of the Nova Process.—Nova Persei and Nova Aquilae are well observed speciments of the type of nova that brightens suddenly and declines more slowly, breaking into rhythmic variations of brightness in the course of the decline. A close study of their spectra during the early stages reveals the geometric history of the outer layers.

Before the maximum brightness the star must expand as a whole. Immediately after maximum the existence of individual jets of material, in which the ejected matter is concentrated (though not confined) can be detected. Some of these jets are associated with maxima in the bright bands; others begin as dark lines, and later, as they move outwards from the shadow cylinder of the star, become bright lines. The ejected matter forms a distinctive velocity pattern, which persists through the fall of brightness and the secondary fluctuations. The latter are found to be the work of the central star, which changes in effective size (probably in consequence of the rise and fall of the effective photosphere as the temperature falls and rises) and ejects material continuously, in quantities that increase with increasing photospheric temperature, in a manner suggestive of expulsion by radiation pressure.

The material that leaves the star undergoes changes of excitation that reflect its changing condition. All the bright lines decrease in intensity as the nova declines; the apparent increase in intensity inferred from the spectrum is a differential effect caused by the more rapid decline in the brightness of the continuum. The permitted lines decline more rapidly than the auroral lines, the auroral lines than the nebular lines.

The pattern of the ejected material during the first few days can be seen in the expanding nebulosity photographed spectroscopically round

Nova Aquilae in 1919-20, and round Nova Persei about thirty years after its outburst. These identifications provide tangible evidence of an actual explosion, and of the reality of the non-isotropic ejection that was inferred from a study of the spectrum lines on plates taken during the first few weeks.

Cause of the Nova Process.—Biermann's theory appears to offer the most satisfactory interpretation of the nova process as the result of a sudden conversion of energy of ionization into radiation in a convectively unstable region. The application of the theory to novae involves the demonstration that the temperature in the critical region for these stars is appropriate for ionization corresponding to the range 160 to 2000 volts.

Calculations based on this theory, and applied to our data for novae, confirm this conclusion. The same calculations for U Geminorum stars show that their temperatures in the critical layer are about at the upper limit required by the theory; those for the novae, on the other hand, are at about the lower limit. For the supernovae it is found that the whole mass of the star (on a reasonable surmise) is but 1/1000 of what should be contained in the convectively unstable layer alone, if Biermann's theory were applicable. We may thus conclude it to be ruled out. There have been other indications that the supernova explosion may have a different origin from those of novae and U Geminorum stars. The latter disturbances are seen to be most probably of internal origin, affecting stars in a particular stage or state. Perhaps the supernovae are set off by some external calamity.

Changes in the Periods of Variable Stars

By Captain Theodore E. Sterne

Some eclipsing variables show change of period that can be reasonably attributed to gravitational perturbations. Tidal forces distort the two components. The distortions extend to the gravitational fields, producing deviations from elliptical motion. The observed deviations of some eclipsing variables, from constant periods, can be rationally and quantitatively explained in this way, and lead to information about the internal distributions of density. Other eclipsing variables exhibit anomalies that arise from the light-times in their orbits about third bodies. Still other eclipsing variables show changes of period that have not been satisfactorily explained.

Cepheid-type variables in certain clusters exhibit systematic increase in period. Such changes must arise from progressive alterations in their "internal constitutions," the latter phrase being interpreted in a general sense so as to include not only progressive changes of density, but also progressive changes in such physical properties of the material as its opacity and energy-sensitivity. Other variables of the general Cepheid type show rapid, regular, and oscillatory changes of period that can be

attributed to simultaneous pulsations in different oscillatory modes.

R Coronae Borealis varies in light in a purely random manner, and can hardly be said to show changes of period since it has no period to change. Some other intrinsically variable stars show very irregular variations of light, and since their periods are badly defined, careful statistical treatments are necessary to show any systematic changes of period. Among such stars are the ordinary long-period variables, like Mira. The intervals between their successive instants of maximum light show considerable dispersion, and their systematic trends, if any, can only be found by using the theory of sampling. Among several hundred long-period variables that have been carefully studied, only a very few show systematically changing periods, and of these some merely fluctuate while only two show a systematic diminution or increase. Both are diminutions. The irregularity of long-period variables suggests that they involve dynamical oscillations about configurations of nearly neutral, or at any rate not highly stable, equilibrium.

Approximate Conjunctions of Venus, Mars, and Jupiter

By R. B. WEITZEL

The dates of approximate conjunctions of Venus, Mars, and Jupiter which have a maximal difference of less than five degrees in geocentric longitude are set forth in a table.

Italicized dates indicate that Mars falls within the period of invisibility between heliacal setting as evening star and heliacal rising as morning star; at the same time, one or both of the other planets might be invisible. Plain dates denote visibility of all three planets. A base 20° north latitude has been used in computing the *arcus visionis* or visibility. Asterisks designate evening stars while morning stars are left unmarked. Incidentally, the geocentric longitude of Venus for each date at midnight Greenwich time is supplied. The columns give, in order, year, month of year, day of month, Julian Day, longitude of Venus.

*—3	*V*	*24*	*1720106*	λ 73°.3
—1	*VIII*	*26*	*1720930*	142.5
1	XI	7	1721734	205.5
57	VIII	18	1742107	110.2
* 82	VI	21	1751180	128.4
*138	III	21	1771542	24.4
142	*IX*	*9*	*1773175*	162.3
*178	VIII	9	1796293	171.4
*182	XII	23	1787890	297.1
198	VI	18	1793546	64.4
*227	X	1	1804243	215.0
243	III	20	1809892	336.3
283	*VII*	*12*	*1824616*	119.6
287	XII	24	1826242	251.1
339	*IV*	*14*	*1844981*	14.9
343	X	3	1846614	154.0
*368	VIII	5	1855687	172.8
384	*I*	*15*	*1861328*	286.6
*424	V	11	1876055	74.5
428	*X*	*25*	*1877683*	207.1
484	VIII	6	1898057	112.1
*509	VI	19	1907140	133.0
533	X	24	1916033	166.3
*565	III	10	1927493	26.9
569	*VIII*	*28*	*1929125*	164.7
*609	XII	12	1943841	299.5

625	*VI*	*5*	*1949495*	66.0
629	XI	18	1951122	199.7
*654	IX	21	1960195	218.4
670	*III*	*9*	*1965443*	339.9
*706	I	9	1978933	338.1
*710	VI	30	1980566	122.2
714	*XII*	*13*	*1982193*	254.6
730	V	16	1987826	14.9
*750	X	16	1995284	252.7
770	IX	23	2002566	157.9
*795	VIII	1	2011644	177.3
811	*I*	*3*	*2017278*	289.1
819	XII	4	2020535	209.9
*851	V	1	2032006	77.5
855	*X*	*14*	*2033633*	209.6
871	III	27	2039276	327.3
911	*VII*	*26*	*2054007*	114.7
916	I	3	2055629	244.9
* 992	III	1	2083446	λ 30°0
* *996*	*VIII*	*16*	*2085075*	167.6
1016	VII	9	2092342	70.6
*1036	XII	3	2099794	302.0
1052	*V*	*23*	*2105444*	67.7
1056	XI	7	2107073	201.7
*1081	IX	13	2116149	221.4
1097	*II*	*23*	*2121791*	340.1
1112	VIII	14	2127442	104.5
*1137	VI	18	2136516	124.1
1141	*XI*	*30*	*2138142*	255.9
1157	V	18	2143790	19.5
1197	IX	10	2158515	159.0
1202	II	18	2160137	291.7
1237	*XII*	*21*	*2173227*	290.5
1253	VI	15	2178882	57.8
*1278	IV	21	2187958	79.9
1282	*X*	*1*	*2189582*	211.2
1298	III	17	2195228	329.4
1338	*VII*	*13*	*2209956*	116.3
1342	XII	23	2211580	246.1
*1374	VI	11	2223073	119.7
*1423	VIII	4	2241024	169.0
1479	*V*	*11*	*2261393*	69.4
1481	*VIII*	*23*	*2262228*	147.5
1483	X	27	2263023	203.9
*1524	II	12	2277741	342.7
1539	VIII	6	2283395	107.8
*1564	VI	8	2292468	127.2
1568	*XI*	*18*	*2294092*	258.3
1624	*IX*	*8*	*2314465*	161.4
1680	VI	13	2334832	60.9
*1705	V	2	2343920	85.2
*1709	X	1	2345533	214.4
1725	III	17	2351179	332.2
1765	*VII*	*11*	*2365905*	118.1
1769	XII	24	2367532	250.2
1825	X	5	2387905	154.8
*1850	VIII	7	2396977	173.1
*1906	V	12	2417343	72.1
1910	*X*	*28*	*2418973*	206.3
*1951	II	12	2433690	343.9
*1991	VI	19	2448427	132.5
*1995	XI	20	2450042	260.6

Washington, D. C.

Planet Notes for April, 1942

By R. S. ZUG

NOTE: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from *The American Ephemeris and Nautical Almanac*.

Sun. Apparent positions of the sun for April 1 and May 1, respectively, are: $\alpha = 0^h\ 39^m1$, $\delta = +\ 4°\ 12'6$; $\alpha = 2^h\ 30^m3$, $\delta = +\ 14°\ 48'8$. The sun will be in Pisces until April 21, on which date it enters the constellation of Aries.

Moon. Phenomena of the moon will occur as follows:

		h	m
Full Moon	Apr. 1	12	32
Last Quarter	8	4	43
New Moon	15	4	33
First Quarter	23	18	10
Perigee	Apr. 4	6	
Apogee	20	4	

Mercury. Mercury will be inconspicuous during April. The planet reaches superior conjunction on April 20.

Venus. Venus will be found in the morning sky during April. The planet reaches greatest western elongation on April 13, 20^h, at which time it will be

46°.3 from the sun. The planet's apparent motion will carry it from Aquarius into Pisces, and, by April 30, almost to the vernal equinox. Venus reaches the ascending node of its orbit on April 20, and for several days thereabouts will be quite close to the ecliptic circle. An occultation of Venus, visible between terrestrial latitudes + 25° and — 42° will occur on April 11, the G.C.T. of conjunction in right ascension being $16^h\ 2^m.5$. Observers in the United States may witness the phenomenon about mid-day as a close approach of the naked-eye planet to the northern limb of the moon.

Data concerning Venus, of interest to observers, are tabulated below:

Date 1942	Distance from earth in miles	Angular Diameter	Fraction of disk seen illuminated	Stellar Magnitude
March 31	53,535,000	29".2	0.42	—4.2
April 10	60,807,000	25.7	0.48	—4.0
20	68,153,000	22.9	0.53	—3.9
30	75,503,000	20.7	0.58	—3.8

Mars. During April, Mars will be visible in the evening sky, and will move eastward in apparent motion through the constellations Taurus and Gemini. The angular diameter of the planet will diminish from 5".3 to 4".6 during the month, while its distance from the earth increases from 165,164,000 miles on April 1 to 189,152,000 miles on May 1. The stellar magnitude will vary from +1.5 on April 1 to +1.8 on May 1.

Mars and Jupiter will be in conjunction with one another on April 4, Mars at the time being to the north of Jupiter by 1° 44'.

Jupiter. Jupiter will be observable in the evening sky during April.

Saturn. Saturn is in the evening sky, and can be seen for a short while after sunset.

Uranus. Apparent positions for Uranus for April 1 and May 1, respectively, are: $\alpha = 3^h\ 41^m.8$, $\delta = +19°\ 28'.1$; $\alpha = 3^h\ 48^m.1$, $\delta = +19°\ 48'.7$. On April 29, Uranus will be situated 1° 39' north of the planet Saturn.

Neptune. Neptune is just past opposition and is to be found retrograding in the constellation Virgo, about 2° east of the +3.8 magn. star, β Virginis.

Occultation Predictions for April, 1942

(Taken from the *American Ephemeris*)

Date 1942	Star	Mag.	IMMERSION Greenwich C.T.	IMMERSION *a*	IMMERSION *b*	IMMERSION Angle E from N	EMERSION Greenwich C.T.	EMERSION *a*	EMERSION *b*	EMERSION Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30', Latitude +42° 30'										
Apr. 7	BD—19°5047	6.9	9 35.6	—2.0	+2.0	36	10 23.7	—2.0	—1.7	324
28	38 Vir	6.2	23 55.8	—0.6	—0.7	144	0 56.2	—1.5	+1.1	265
Occultations Visible in Longitude +120° 0', Latitude +36° 0'										
Apr. 6	192 B.Oph	6.3	5 43.9	—1.2	+3.3	44	6 16.8	+0.3	—1.4	339
7	BD—19°5047	6.9	8 53.2	—1.8	+2.0	56	9 54.2	—1.4	—0.5	311
19	70 Tau	6.4	1 40.1	—0.1	—2.4	124	2 30.8	—0.4	0.0	229
24	90 B.Cnc	6.3	1 9.9	—2.9	+1.8	57	2 5.1	—0.8	—4.1	339
28	38 Vir	6.2	23 53.8	+0.1	—2.9	174	0 23.1	—1.3	+3.8	230
29	*k* Vir	5.9	3 4.9	—2.5	+1.9	68	3 55.2	—0.6	—2.6	346

OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′

Apr.	4	γ Lib	4.0	11	38.3	..	..	34	12	3.9	..	..	358
	5	24 Sco	5.0	14	35.6	—1.3	—0.8	87	15	44.9	—1.0	—1.4	281
	7	89 G.Sgr	6.5	14	20.0	—2.2	—0.7	104	15	36.7	—1.6	0.0	244
	8	267 B.Sgr	5.9	11	6.6	—1.3	+1.4	78	12	21.6	—1.6	+0.6	278
	19	75 Tau	5.3	2	59.9	—0.9	—0.3	66	4	3.3	—0.1	—1.8	287
	19	264 B.Tau	4.8	4	8.9	0.0	—1.8	111	5	4.4	0.0	—0.4	244
	21	BD+18°1112	6.4	4	43.2	—0.5	—1.5	103	5	48.5	—0.2	—1.2	270
	22	110 B.Gem	6.2	5	23.9	—0.5	—1.8	114	6	28.1	—0.3	—1.2	268
	26	44 Leo	5.9	5	19.0	—3.0	+1.0	63	6	9.1	—0.3	—3.9	348
	28	13 Vir	5.9	10	42.1	—0.4	—1.4	102	11	40.0	—0.1	—1.7	297
	29	*k* Vir	5.9	2	20.9	—0.7	+0.3	115	3	27.3	—1.1	+0.2	293

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

FIREBALL OF 1941 JANUARY 21

On 1941 Jan. 21/22, 7:04 P.M., E.S.T., a brilliant meteor was observed from various points within a couple of hundred miles of Washington, D. C., and enough reports came to me to justify a solution for its path. The best report came from a ship, S1, off Cape Hatteras, N. C., in λ 75° 10′ W, φ 35° 19′ N; from Frederick, Md., S2, Mrs. J. H. Apple; from Washington, D. C., Mrs. C. Cummings, S3; from Mt. Rainier, Md., J. A. Duerkson, S4; and from Cambridge, Md., H. J. Warmuth, S5. Several other reports appeared in Baltimore and Philadelphia papers but some of the people mentioned therein, to whom requests for further information were sent, failed to reply. As often happens one report has to be made the keystone of the solution, in this case S1, so pertinent parts are quoted from the *Hydrographic Bulletin, U.S.N.*, in which it appeared: ". . . 0304 G.C.T., an unusually bright meteor . . altitude 35°, bearing 338° true, descended vertically, leaving a faint yellow streak. The brightness . . . grew until it reached an altitude of 18°, when it appeared to disintegrate with a bright flash . . . became green and continued descending. The entire spectacle lasted about 10 seconds . . . disappeared about 3° above horizon with a bright flash . . . trail remained visible for about 4 or 5 seconds." From S2 it was reported to fall vertically and went below a roof later measured to have h = 6° or 7°, in about a = 320°. This observation came through Miss L. B. Allen, director of Williams Observatory, who went to see the observer and measured the angles pointed out. I used h = 6° for end point at S2. S4 reported it was first seen at h = 5° or 10°, motion slightly to right as it fell. Angular diameter slightly less than half that

of Moon . . . yellowish-red, oblong in shape and followed by white light of less intensity. S5 was inside house but saw flash through window . . . flashed white, but no train remained by time he could get outside. Thought it exploded N. of S.W. at about h = 60°. About 4 minutes after a sharp rumbling was heard. (Our solution would give h = 45° for explosion point from S5 and the time it would take sound to reach S5 from this point 5 ± minutes, which is a fair check for this sort of work.) The report from S3 was confirmatory of azimuth of path. Other incomplete reports merely told of brilliance of object, etc.

On making a plot to scale of the region covered and entering the stations, by great good fortune it was found that the azimuth of S1 from S2 was within 1° of 338°, which figure was given by S1 as the bearing of the plane of meteor's path. thus fully confirming the vertical fall as seen from each. By combining h = 45° from S4 with h = 32° from S1 the starting point was found and the observations from S1 and S2 gave the ending point. A graphical solution was first made by which the approximate position of the path was determined; then corrections for curvature were added to the observed altitudes and a second solution for heights was made. The data justified no further attempt at improvement. We then derive:

Date	1941 Jan. 21, 10:04 P.M., E.S.T.
Began over	λ 76° 17′ W, φ 37° 26′ N at 183 km height
Ended over	λ 76° 36′ W, φ 38° 00′ N at 15 km height
Length of path	184 km
Proj. length of path	75 km
Explosion point	93 km
Duration	9.5 sec
Apparent velocity	19.4 km/sec
Radiant (uncorrected)	a = 338°, h = 66°; α = 99°, δ = +16°

The comparative nearness of the radiant to the zenith, in the circumstances, made application of zenith correction a needless refinement.

The two points of outstanding certainty are the azimuth of the plane of motion, hence of the radiant, and the very low height of end point. We might well infer that meteorites from this object reached the ground in the extreme northern part of Northumberland County, Va., between the villages of Callao and Kinsale, if our solution is approximately correct. Mr. Walter H. Haas of my staff first made the complete solution. Later I did this independently and came to substantially the same results. I wish therefore to give him full credit for the solution of this case.

Fireball of 1940 September 22

A very fine fireball was seen on 1940 Sept. 22/23 at 9:27 P.M., E.S.T., and reported by four persons. The abbreviated observations follow: S1 λ 74° 57′ W, φ 40° 23′ N, T. MacDowell, ". . . appeared just below δ Urs. Min. . . traveled rather slowly past α Dra. then burst into 3 or 4 parts, the largest . . . on down between ζ and ε Urs. Maj. . . brilliant green all the way to horizon . . . reflected light almost equal to full moonlight . . ." S2 λ 75° 09′, φ 39° 46′, P. M. Duthie (in auto) ". . . falling in N.W. . . . almost as large as Moon . . . greenish . . . dropped straight down (vertically meant??), disappearing before it touched horizon or was obscured by trees . . ." S3 λ 74° 15′, φ 40° 27′, R. E. Taylor (in auto) ". . . just above Big Dipper running through it until it reached Can. Ven., when it vanished . . . about size of Jupiter, white . . . 10 seconds duration and very short train. . ." S4 λ 76° 43′, φ 42° 45′, C. R. Gregory (in auto) ". . . glanced back over my left shoulder . . . saw end of fireball path. Road runs a

little S of E. No trail. I thought it was coming almost exactly towards me and perhaps with a twisting motion. . . ."

Attempts were made to derive heights from these reports but unsuccessfully. Enough is known to say that it ended probably not far to S± of Rochester, N. Y., at about 30 ± 10 km height, that the azimuth of the radiant was 315°±, and that it started over northern Pennsylvania perhaps 40 ± miles south of the New York border, at an altitude of about 100 km. Near the path it must have given greenish or white light comparable to moonlight, and the object burst. The radiant, evidently, can not be determined with any accuracy. This object must have been seen by thousands of intelligent people but these four were the only reports received. For this fireball there was, unfortunately, no request for observations published in the papers, and it seems that immediate publicity throughout the region in question is necessary if we wish enough data to arrive to make a solution in the average case.

Fireball of 1931 June 10

Among the many fireballs for which a certain number of reports came is that of 1931 June 10. My early attempts at a solution were failures, but as the body left a long enduring smoke train, visible at least a quarter of an hour, I have studied the reports again and have derived a rough path, which in the circumstances has some value. This path was wholly over New York State and probably passed over Syracuse. I am indebted to C. R. Gregory for putting notices in the local papers and most efficiently acting as A.M.S. representative. It is due to his efforts that the reports were gathered. It would serve no useful purpose to quote the full observations, only the stations—all in New York—and the observers will be given, except for the notes on the train. Auburn, S1, J. Kavanagh and H. Warter; Ithaca, S2, Phillips and DeF. G. Rundle; Cato, S3, S. B. Long; Aurora, S4, Mrs. G. Jump; Syracuse, S5, Miss B. Dotterer, Miss A. Thompson and two names unknown; Cortland, S6, R. H. Ryan; Fulton, S7, J. O. Brian and W. Shand; Canastota, S8, D. C. and Mrs. Smith. S4 alone gave full angular data, S2 the coordinates of end (?) point, S5 reports that it passed through zenith, S3 gave definite directions and the rest rough directions of motion. From these the following very approximate results are derived:

Date	1931 June 10 8:11 ± 4 P.M., E.S.T.
Began over	λ 75° 46′ W, ϕ 42° 41′ N at 83 km
Ended over	λ 76° 52′ W, ϕ 43° 29′ N at 56 km
Length of path	148 km
Proj. length of path	145 km
Apparent velocity	Probably large
Radiant (uncorrected)	a = 315° h = 11°
Radiant (corrected)	a = 315° h = 7°; $\alpha = 250°$, $\delta = -25°$

By chance, the two values for the end point, or at least the point where the object "burst" or had a large increase in brightness, check within less than 1 km. The usual descriptive term used was "ball of fire" and as, in the twilight, the stars were not visible, the fireball must have been very bright and had an appreciable apparent diameter. The few who gave colors are wholly contradictory. As the importance of this fireball is mostly due to the smoke train left, description of this will now be quoted.

S1 A, ". . . left in its wake a long, at first almost straight trail of light, of the same color as itself, *i.e.*, bluish-white . . . trail was apparently 15 or 20 feet long . . . visible fully 10 min. Almost straight at first, after a while it began to wave slowly like a long wisp of smoke, blown by the wind. At times it ap-

peared perfectly motionless . . . (later) the waving or curling became more noticeable until finally . . . it had wound itself into a spiral formation, something like an irregularly shaped S."

S1 B, "The streak of smoke should judge 15 feet long and lasted about 15 minutes."

S2 A, "Very bright train persisted for nearly 10 min."

S2 B, "Left a broad streak of light after it resembling smoke. The light streak remained for 5 minutes gradually curling up and disappearing."

S3, "The smoke was visible for about 15 minutes. At first the trail left had the appearance of a crack in the sky but (later) it became wider and more crooked and had the appearance of a 'smoke screen' dropped from an aeroplane."

S4, "A trail remained visible for 10 min. or more 'like a snake.' As it grew darker the trail was seen to extend farther N, nearly to the horizon, and was visible 20 min. or more; this trail . . . not a straight line, but had branches at right angles."

S5 A, ". . . it was like a streak of smoke forming in different positions."

S5 B, ". . . it left a straight line, then it kept curling up till it looked like a streak of lightning."

S6, ". . . the trail . . . in sky for quite a few minutes."

S7, ". . . like a streak of lightning . . . wavy and zigzag. It remained in sky for a while, then diffused like smoke.

S8, "The trail remained suspended, perfectly still in the sky for about 15 minutes."

If S8 is correct, it would appear that most of the motion of the train was in the vertical plane, this however is contradicted by the two observers at S5. But in any case the winds affecting the train had low velocities. I am wholly unable to deduce their directions from the data at hand. Evidently there was no considerable motion in any part of the train. The path was not far from horizontal, and all included within a stratum 27 ± km thick. If the altitudes given are correct, this train must have been below the lower (average) limit of night trains, *i.e.,* 74 km, and just at the upper (average) limit of day trains, *i.e.,* 57 km. Also it appeared in twilight. It will offer another of the intermediate cases which make separate explanations for day and night trains more difficult. (See paper mentioned in last paragraph in which this fireball is No. 1004.) In closing this case I must again warn that the accuracy of the derived data is extremely questionable, and I only feel justified in publishing them due to the general importance of train phenomena.

My paper on long enduring trains, dealing with the 1336 cases that could be found, has just appeared in *Proceedings of the American Philosophical Society,* Vol. 85, Part 2, pages 93 to 135, 1942. Reprints of this paper, on which many years of work were spent, will be mailed to members of the A.M.S. who have paid their 1942 dues and to others entitled to receive it.

Word has come of the recent death at 89 years of age of one of our most faithful members, Wm. R. Stone of Santa Barbara, California. So is removed from our ranks the man who holds, so far as my knowledge goes, the world's record for an active meteor observer in that he made regular observations up to the age of 88. Nor were his periods of observing short, they usually covered from 3 to 4 hours, well into the second half of the night. His last report was

for 1941 Jan. 2, 11 to 15 hours, on the Quadrantids! What an example he set to the average A.M.S. member who is from less than a quarter to perhaps half his age. The news of his death was received with real sorrow.

Flower Observatory, Upper Darby, Pennsylvania, 1942 January 28.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
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Meteorite Detectors*

By LINCOLN LA PAZ
Department of Mathematics, Ohio State University, Columbus

ABSTRACT

Mathematical investigation of the vertical distribution of iron meteorites in the Earth indicates that the amount of meteoritic iron buried below maximum plow depth greatly exceeds the amount above this level. Thus, there is urgent need for instruments capable of detecting deeply buried iron meteorites. In this paper, a brief review of the physical principles underlying the operation of such meteorite dectectors is given. Difficulties encountered in field use of such equipment are discussed on the basis of experience gained as Director of the first Ohio State University Meteorite Survey; and results secured in an investigation of the Odessa, Texas, Meteorite Crater, made at the invitation of Professor W. D. Mateer, Supervisor of the Meteorite-Crater Project of the University of Texas in September, 1939, are summarized.

Both the well-known fact that many old meteorites are plowed up from considerable depths and the penetration data secured from the study of observed falls show that meteorites do not merely "fall to the Earth" but that they actually penetrate into it. Where several meteorites of widely different masses happen to hit equally resistant Earth targets—as has occurred in certain of the great meteoritic showers—the measured depths of penetration of the various pieces suggest that, for a meteorite, penetration is proportional to the cube root of the striking mass. It is not difficult to reach essentially the same conclusion from theoretical considerations.

An immediate inference is that, in general, really big meteorites bury them-

*Read as the first part of *A Preliminary Report on an Instrumental Search for Meteorites* at the Seventh Meeting of the Society, Columbus, Ohio, December, 1939.

The writer wishes to express his appreciation to F. O. Wisman for valuable suggestions made in the course of the preparation of this paper. He wishes also to acknowledge a grant made by the Graduate Council of Ohio State University to cover expenses incidental to the publication of this report.

selves deeply at impact. On the other hand, the number of large meteorites which fall is small in comparison with the total number of meteorites of all sizes reaching the Earth. As it is not immediately apparent which of these influences will predominate in determining the vertical distribution of meteoritic material in the Earth, a mathematical investigation is necessary to decide whether the average meteoritic mass in a stratum situated at considerable depth is greater than or less than the average meteoritic mass in a layer of the same thickness near the surface of the Earth.

Such an investigation[1] for the irons, based on the usual simplifying assumption of spherical shape, shows that if 1078 cm. $\geqslant B > A \geqslant b > a$, then the ratio, q, of the total amount of meteoritic iron lying in the stratum between depths of B and A cm., to the total amount of meteoritic iron in the stratum between depths of b and a cm., is given by the formula:

$$q = \frac{\int_A^B \int_{r_1(x)}^{r_2(x)} N_0(r)\,[\rho(r)]^2\,dr\,dx}{\int_a^b \int_{r_1(x)}^{r_2(x)} N_0(r)\,[\rho(r)]^2\,dr\,dx},$$

where $\rho(r) = \{r^2 - [d(r) - x]^2\}^{\frac{1}{2}}$; $d(r) = 5r$; $r_1(x) = \frac{1}{6}x$; $r_2(x) = \frac{1}{4}x$. In this formula, $N_0(r)dr$ represents the number of iron meteorites with radii between r and $(r + dr)$ which strike the entire Earth annually.

By utilizing several forms of $N_0(r)$, consonant with observational data, values of q were computed with $A = b = 25.4$ cm. The results obtained indicated that perhaps 100,000 times as much meteoritic material lies buried below maximum plow depth (25.4 cm.) as occurs above this depth. Altho the percent of the total number of recovered meteorites found by the plowman is large, the actual number of meteorites thus discovered is surprisingly small if account is taken of the vast tracts of land under cultivation. In view of the fact that the areal extent of systematic excavations carried to depths exceeding 25.4 cm. is, and probably will long remain, vanishingly small in comparison with the enormous acreages plowed up, it is clear that there is urgent need for instruments designed to detect the presence of deeply buried masses of meteoritic iron.

An iron meteorite buried in the Earth is an example of an object hidden in an opaque medium. Obviously, it is possible to detect such an object only in so far as some of its physical properties differ from those of the medium in which it is embedded. One such property, in the case of a buried siderite, is its magnetic permeability, which is very large in comparison with that of rock or soil. For example, the magnetic permeability of unoxidized meteoritic material in the Canyon Diablo, Arizona, area was found to be over a million times greater than that of the sedimentary rocks in which the great Arizona Meteorite Crater is located.[2] The unusually large magnetic permeability of a buried iron meteorite produces changes in the natural magnetic field of the Earth in the vicinity of the meteorite, and these changes, if sufficiently pronounced at the surface of the Earth, may be measurable by means of devices called "magnetic balances." The oldest and simplest such balance is the ordinary dip-needle, and, in meteorite hunting, as in iron-ore finding, this relatively crude device seems to have been the first instrument used to aid the searcher. In spite of poor performance, ordinary dip-needles are reported to have been employed at Canyon Diablo as late as 1932-3;[3] but

long before this date, use had been made of such refined equipment as the Hotchkiss Superdip[4] and the various forms of magnetometer. The latter instruments in particular have performed satisfactorily and would seem well adapted for such definitely localized investigations as the search for *buried* meteorite craters surmised to lie in the immediate neighborhood of *known* meteorite craters.[5]

In addition to magnetic effects, a buried iron meteorite may, under suitable conditions, produce measurable electric effects at points on the Earth's surface above it. It is not difficult to itemize such possible electric effects. The fundamental electric phenomena are 4 in number: *first,* the field of dielectric force set up by an electric charge; *second,* the current (and associated magnetic field) set up by such a charge in motion; *third,* the electromotive force (and associated notion of potential) appearing when a current passes through a resistance, as it must in any physical situation; and, *finally,* the electric-cell effect, which arises when 2 dissimilar conductors are arranged to produce an electromotive force by electrochemical or thermoëlectric action.

FIG. 1

Octahedrites found in a 12-hour instrumental search of the Odessa, Texas, Crater area. The steel tape shown in the second row is 36 inches long. The tents in the background are those used by W.P.A. laborers employed in excavating the Crater.

The first and last of these effects offer no promise as far as the detection of meteorites is concerned. The *potential-drop-distribution method* based on the third effect is applicable to only very extensive objects and for such objects only in case the specific resistance, ρ, of the object differs greatly from that of the surrounding medium. In the case of an exceedingly large, homogeneous, metallic meteorite, these conditions are approximately fulfilled, but there seems little likelihood that the potential-drop method will ever become important to the meteoriticist because of the complicated and tedious field technique and the expensive equipment it involves.

There remains as a practical source of meteorite-detection methods only the

effects in the second category. We shall refer to methods based on these effects as *electromagnetic methods.* Such methods may be immediately subdivided into those which are concerned with the differential of flux density and those which depend on distortion of the magnetic field.

Fundamentally, the flux-density method rests on the fact that if the flux originating from a coil is caused to change slightly, then the coil will exhibit an increment of inductance directly proportional to the change in flux. To measure this increment of inductance, one of the modifications of the Wheatstone bridge may be employed. Certain of the "dud-detectors," designed to locate unexploded shells buried in fields of which it was desired to renew the cultivation, after World War I, utilized this scheme. Their apparently unsatisfactory performance is explainable by the fact that it is impossible to build a search-coil with pure inductance. Such a coil has associated with it always an internal resistance and a distributed capacity. As a result, the bridge employed can be balanced with a given setting for one frequency only. At all other frequencies, the bridge is out of balance, and the instrument reacts in the same manner as if a metallic object were brought near it.

A more promising flux-density method would seem to be the beat-frequency-oscillator system, in which the inductance of the search coil is used to control the frequency of a vacuum-tube oscillator. Unfortunately, many and grave difficulties are encountered in the development of instruments of this type.

We come, finally, to instruments designed to measure the magnetic-field distortion produced by proximity to metallic masses. It happens that all instruments constructed or tested at the Ohio State University (and, in fact, as far as the writer is aware, all meteorite detectors which have functioned satisfactorily in the field) are of this type. It is well known that when a ferromagnetic mass is brought into the magnetic field surrounding an energized coil, the flux from the coil is attracted and reinforced by the mass in question. As a result, the coil giving rise to the field will exhibit a *positive* increment of inductance. If the field intensity oscillates, Foucault currents will be induced in the meteorite, and the existence of these currents will set up a counter magnetomotive force in such a direction as to oppose the impressed field and hence to neutralize a portion of it. This "eddy-current effect," as it is termed, repels and diminishes the impressed field. As a result, the coil exhibits, among other things, a *negative* increment of inductance. The positive effect is independent of the frequency of the energizing current, but the negative effect is proportional to this frequency. Hence, for a meteorite of given size, there exists a frequency of operation at which the net distortion and, therewith, all possibilities of detection vanish. This is only one of a number of facts which must be taken into account in deciding at what frequency a magnetic-field-distortion instrument is to be driven. However, a thoroughgoing discussion of these matters is not within the province of this preliminary account, and, in what follows, we shall assume simply that a frequency of operation at which, among other things, the net distortion is different from zero is employed and examine the 2 chief means utilized at present for the measurement of this distortion.

On the one hand, commerical instrument-makers have specialized in the construction of what may be called *perpendicular-coil detectors.* These instruments consist of a horizontal (vertical) "power" coil or transmitter rigidly joined to a vertical (horizontal) pickup coil by handles having a length of several coil

STATE-WIDE PALEONTOLOGIC-MINERALOGIC SURVEY OF TEXAS
FIELD SPECIMEN RECORD

Odessa Crater Site No. 1 Ector County

Field Specimen No.	Kind of Specimen	Depth From Original Sur. In Ft. & In.	Mass ~~xxxxxxx~~ Field		Photo-graph No.
1	Octahedrite	8"	1# 6oz.	near west rim	
2	"	1' 6"	29# 6"	sw. strip	✓
3	"	11"	7# 5"	South strip	
4	"	8"	4# 2"	west "	
5	"	1' 2"	7# 2"	" "	
6	"	1'	6# 6"	" "	
7	"	1' 2"	18# 2"	" "	
8	"	1' ¼"	10# 15"	" "	
9	" (much shale)	1' 7½"	24#	north "	
10	" (some shale)	1'	1#	" "	
11	" (little shale)	8½"	14"	" "	

Exact Location of Work Site:

Section 5, Block 43, T3S, T. & P. R.R. Co. Survey (v. sketch map #1)

Date 390914-17 Signature Lincoln LaPaz

FIG. 2
Weight and Depth of Burial Data for 11 of the Meteorites shown in Fig. 1.

diameters. In the absence of meteoritic material, such instruments may be brought to a condition of balance in which none of the flux emanating from the power coil is linked by the pickup coil. In this condition the mutual inductance is zero and no signal is induced in the pickup system. If, now, the instrument is carried over a meteorite, the resultant field distortion results in linkage of power-coil flux by the pickup coil. A voltage is thus induced in the pickup system and, after suitable amplification, appears as a signal tone or acts to deflect an indicator needle. Of several instruments of this sort exhaustively tested by the writer, one, which we shall refer to as no. 1, gave superior performance in comparison with all of the others. In spite of this fact, 2 no. 1's which were carried on the 1939 expedition were found, on the basis of field tests, to be open to the following objections:

(1) Altho the no. 1 was the lightest perpendicular-coil instrument tested, its weight of more than 25 pounds, supported solely by the hands of the operator, was at all times too heavy for comfort and effectively prohibited use of the instrument on steep mountain slopes like those along the Stanislaus River in California.

(2) Even if the weight of no. 1 were cut in half, its size and shape and the necessity of employing both hands to support it would preclude its use on mountain slopes like those bordering the Stanislaus River (where it is imperative that the operator have his hands free to aid him in ascending the mountainside) or in brushed areas like those in which the lost Port Orford, Oregon, meteorite is situated.

(3) The no. 1 required frequent adjustment when carried over ground where the Earth conductivity varied rapidly, as in the Canyon Diablo Crater area. While it is possible for the operator to make the requisite adjustments, the task is an awkward and time-consuming one and in practice is soon delegated to an assistant, thereby decreasing the number of independent searches which can be maintained.

(4) The battery drain for no. 1 is larger than is desirable.

(5) For no. 1, exceptional rigidity of the supporting handles and of the instrument panels, which form part of the coil containers, is required, as a displacement of one of the coils relative to the other or of an instrument panel with respect to the neighboring coil will produce a false signal. To avoid increasing the already burdensome weight of no. 1, very light construction is used in the panels and their supports; to permit compact packing of the entire instrument, folding handles are supplied as standard equipment. As a result, the requisite degree of rigidity is difficult to attain even when the instrument is operated under favorable conditions.

(6) False signals are given by the indicator needle in response to even very remote flashes of lightning.

(7) Because of the high frequency at which no. 1 operates, it cannot be employed to search for iron meteorites buried in *moist* ground and is almost unmanageable when used over soil containing large amounts of such iron compounds as occur in the neighborhood of the Canyon Diablo, Arizona, and Odessa, Texas, Meteorite Craters.

In several investigations where search has been made primarily for ferromagnetic masses such as unexploded airplane bombs and iron meteorites, instruments of quite different design from the perpendicular-coil detectors have been used with great success. As far as the writer has been able to ascertain, the forerunner of all such instruments is the "N.A.C.A. Bomb Detector," designed in 1930 by

Theodorsen,[6] "for the immediate purpose of locating unexploded bombs which were known to have been dropped from airplanes at targets in close proximity to the site of the new Seaplane Towing Channel at Langley Field, Virginia."

FIG. 3

The "accordion meteorite," found in the instrumental survey of the Odessa Crater. Professor Mateer's large rock-hammer gives the scale.

In the original Theodorsen bomb-detector, 3 coils were wound symmetrically on a hollow, cylindrical, wooden frame 3 inches thick, 3 feet in diameter, and 1½ feet high. The central or power coil was energized by a special 110-volt, 6-ampere generator furnishing 500 cycle-per-second current. The strong alternating field supplied by the power coil induced electromotive forces in the neighboring pickup coils, which were so connected that only the difference of the E.M.F.'s appeared across a telephone receiver connected in series with the pickup coils. In a condition of balance, one pickup coil was an "image" of the other with respect to the

central power coil and no current flowed through the receiver. When the device was carried over a buried bomb, the resulting distortion of the magnetic field destroyed this condition of balance and a signal was heard in the phones. In view of the thickness of the cylinder on which the coils were wound, 2 men were required to carry the instrument, which was suspended from a ladder-like frame by means of ropes. In view of the great weight of the generator used, a large power-supply truck was necessary in field work.

A brief calculation of the cost and the weight of the apparatus described in the last paragraph will convince one that, no matter how satisfactory its performance, it is not suitable for use by the meteorite hunter. However, many possible modifications of the N.A.C.A. instrument speedily suggest themselves and several of these have been developed into first-class meteorite detectors at Ohio State University. In one direction, *large scale,* 3-coil instruments have been constructed which can be energized by standard, portable, gas-engine-driven 110-volt generators, small enough to be mounted in the luggage compartment of a motor car. In another direction, *portable* 3-coil instruments energized by vacuum-tube oscillators and small enough to be carried in a knapsack have been built. Search coils of all sizes, from the 10-inch coil used for demonstration purposes in the booth of the Society for Research on Meteorites at the 1939 (Columbus, Ohio) meeting of the American Association for the Advancement of Science, to the largest-scale coils employed in the field, can be plugged into such oscillator units as easily as one can change the size of an electric-light bulb in accordance with the level of illumination desired. Finally, in a still different direction, a variation of the vacuum-tube meteorite detector, employing only *one* pickup coil and *one* power coil, has been constructed at Ohio State University since the return of the First Meteorite Expedition, by F. O. Wisman. This 2-coil instrument has less than half the battery drain of any commercial instrument tested by the writer, weighs less than 15 pounds, and can be used anywhere a man can walk or climb. When a search coil 10 inches in diameter is employed, the instrument will detect a light-weight, cast-iron cistern cover at a distance of 4 feet under favorable conditions and will clearly pick up a 15-pound Odessa iron buried at a depth of 12 inches in a water-filled hole in a muddy field. This last performance (which has been approached by certain of the 3-coil instruments) will make clear that the Ohio State University meteorite detectors are not open to the seventh objection raised against the perpendicular-coil instruments. Furthermore, they are almost, or quite, free of the second, third, fifth, and sixth objectionable features mentioned in the discussion of the perpendicular-coil instruments.

It is natural to inquire whether results obtained by use of meteorite detectors in the field have justified the time and labor spent on their design and construction. An adequate answer to this question appears to be given by the following statements: In the years between 1921 and 1939, the Odessa Crater area was repeatedly searched without instrumental aid by several of the most diligent and successful meteorite hunters. Returns were negligible, the largest specimen recovered up to September, 1939, having, according to H. H. Nininger, a weight of only 8¼ pounds. In the first 2 weeks of September, 1939, several scientists and approximately 30 W.P.A. workers employed on the Meteorite-Crater Project searched diligently, but without instruments, for meteorites not only at the Crater itself but over much of the land adjoining the Crater. The only meteorite found was the tiny fragment weighing less than one pound, second from the right, in the

lowest row shown in Fig. 1. On September 14, 1939, at the invitation of Professor W. D. Mateer, then in charge of the Crater Project, a preliminary instrumental survey of the Crater was begun by members of the first Ohio State University Meteorite Expedition. In 12 hours of actual field work, 13 meteorites and a large number of "shale balls" were found, all but one by the use of detectors. 12 of these meteorites are shown in Fig. 1, and details as regards weight and depth of burial for 11 of these specimens are given in Fig. 2, which illustrates also the convenient field-specimen record-sheet used by Mateer. The thirteenth iron, (see Fig. 3) a remarkable specimen nicknamed the "accordion meteorite," was not removed from the limestone in which it had embedded itself to a depth of over 3 feet, but was estimated to weigh between 300 and 500 pounds.

REFERENCES AND NOTES

[1] La Paz, L., *Astr. Nach.*, **267**, 107-12, 1938.

[2] Jakowsky, J. J., *Trans. Am. Inst. Mining and Metallurgical Engineers*, **97**, 63, 1932.

[3] Such use is described in a letter written me by Shirl Herr in 1935.

[4] For a description of the Hotchkiss Superdip, consult Stearn, N. H., *Bull. Am. Assoc. Petroleum Geologists*, **13**, 659, 1929, and *Trans. Am. Inst. Mining and Metallurgical Engineers*, **97**, 169, 1932.

[5] Since these lines were written, a magnetometric survey has been credited with the discovery, in 1940, of a small buried crater situated near the main Odessa, Texas, Crater.

[6] Theodorsen, T., *Jour. Franklin Inst.*, **210**, 311, 1930; *Proc. Nat. Acad. Sci.*, **16**, 685, 1930.

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Lest We Forget: In the issue of POPULAR ASTRONOMY of five years ago, we find reported for the month of January, 1937, a total of 4393 observations submitted by 70 observers. To recall further statistics to our minds, listed below are the records as they appear in the January, February, and March issues for the past three years.

January	1940	70—5008	received during	November	1939
February	1940	70—4101	" "	December	1939
March	1940	65—3864	" "	January	1940
January	1941	63—4061	" "	November	1940
February	1941	50—2531	" "	December	1940
March	1941	48—2197	" "	January	1941
January	1942	52—2884	" "	November	1941
February	1942	46—2484	" "	December	1941
March	1942	39—2870	" "	January	1942

Some reports are still being gratefully received from South Africa and India, as well as from Mexico and Canada, but practically all other reports from abroad have ceased. With this in mind, it is all the more important that American ob-

servers do everything in their power to swell the numbers of observers and observations.

From communications received in the Recorder's office, we are becoming aware that already our American observers too are feeling a great press of work in our defense effort—seven day a week jobs—air raid warden and other volunteer work—active duty in the services—changes of occupation and abode necessitated by the country's defense effort. All the more then must these observers and others realize that even one night's work a month will aid the Association and the work it is doing.

No one knows what the next few years may bring to astronomical investigation and research. But until such time that we are all—young and old, man and woman—engaged in defense work for 24 hours a day, let us one and all make an all-out effort to keep observations coming in at as high a level as it lies within our power to do. Let us do our part to maintain the continuity in the observed light curves of our variables, if not with as many observations, at least with as few gaps as possible.

Observers and Observations received during January, 1942:

Observer	Var.	Est.	Observer	Var.	Est.
Blunck	9	11	Koons	16	25
Bouton	40	57	Manlin	41	43
Cave	2	2	Mason	30	38
Chandra	53	84	Maupomé	135	198
Cilley	85	301	Meek	16	26
Cousins	27	49	Nadeau	20	35
Escalante	45	50	Palo	5	5
Fernald	157	279	Parker	20	23
Ford	28	31	Parks	22	48
Griffin	25	25	Peltier	114	165
Harris	14	14	Petzold	2	3
Hartmann	139	169	Rosebrugh	12	26
Holmes, Mrs.	6	6	Smith, F. P.	8	8
Holt	149	260	Stahr, Miss	3	3
Houghton	53	101	Topham	27	27
Houston	17	17	Vohman	4	4
Irland	18	22	Webb	12	12
Jones	41	68	Weber	34	34
Kearons, Mrs.	62	119	—		—
Kelly	12	16	39	Totals	2870
deKock	62	466			

February 16, 1942.

Comet Notes

By G. VAN BIESBROECK

Comet 1942 *a* (Whipple). The first new comet of the year was found by F. L. Whipple on sky patrol plates taken at the Harvard College Observatory. The announcement came on January 31 and gave the following telegraphic information:

1942 Jan. 25 at $10^h\ 48^m1$ U.T.
$12^h\ 59^m\ 8^s0 + 23°\ 53'\ 0''$
Daily motion $1^m\ 17^s$ west and $0°\ 10'$ south.
Magnitude 10. Diffuse with central condensation.
Tail less than 1° in length.

The image of the comet was also found on patrol plates taken December 28, 1941, and January 17, 1942, which enabled R. N. Thomas to compute a first parabolic orbit:

ELEMENTS OF COMET 1942 *a* (WHIPPLE)

Perihelion time 1942	April 30.886 U.T.	
Node to perihelion	223° 26′	1942
Longitude of node	340 8	
Inclination	79 26	
Perihelion distance	1.4452 A.U.	

Since these depend on an interval of twenty-eight days the orbit should be reliable, although the positions obtained from small-scale plates are only approximate. R. N. Thomas also gave an ephemeris for February which I have extended for March:

EPHEMERIS OF COMET 1942 *a* (WHIPPLE)

1942		α h m	δ ° ′	Distance from Sun	Distance from Earth	Mag.
Mar.	2	10 43.0	+ 8 7	1.67	0.68	7.5
	6	10 15.7	4 25	1.65	.66	7.4
	10	9 48.2	+ 0 31	1.62	.66	7.3
	14	9 21.3	— 3 23	1.60	.67	7.3
	18	8 56.2	6 53	1.57	.70	7.3
	22	8 33.8	10 3	1.55	.73	7.3
	26	8 14.2	12 47	1.53	.78	7.4
Mar.	30	7 57.4	15 6	1.51	.83	7.5
Apr.	3	7 43.3	—17 4	1.50	0.87	7.6

This shows that at that time the comet will be well situated and easily accessible to telescopes of moderate size. Crossing the constellations of Sextans, Hydra, and Puppis in a south-western direction, the comet will remain of nearly the same brightness during April. Estimates of brightness as compared with stars of nearly the same intensity are highly desirable and will probably best be obtained with the help of binoculars. Cloudy weather has prevented observations at Williams Bay so far.

Of the comets previously under observation only one will remain visible in March. That is PERIODIC COMET SCHWASSMANN-WACHMANN 2 for which an ephemeris was given on p. 104. Its brightness corresponds well to the ephemeris value so it can be seen only in good-sized telescopes.

COMET 1941 *d* (VAN GENT) is dropping so rapidly in brightness that no further observations are expected in March. When last recorded here on February 8 it was reduced to a small round coma not brighter than 15^{M}.

The computing section of the British Astronomical Association is to be congratulated on continuing the care of the expected periodic comets in spite of the increasing difficulties caused by the war. The *Handbook* for 1942 was welcomed here late in January. It contains extended ephemerides for five periodic comets. Of these SCHWASSMANN-WACHMANN 2 is already under observation. Next in order of perihelion times are FORBES (April 16), GRIGG-SKJELLERUP (May 23), WOLF 1 (June 7), and REINMUTH (December 5).

The first one is still unfavorably situated. COMET GRIGG-SKJELLERRUP will be in a good position in March and may even be recovered before then. F. R. Cripps gives the following ephemeris:

EPHEMERIS OF PERIODIC COMET GRIGG-SKJELLERUP

1942		α h m	δ ° ′
Mar.	6	5 12.6	— 3 7
	14	5 17.5	— 1 44
	22	5 25.2	— 0 16
Mar.	30	5 35.7	+ 1 16
Apr.	7	5 48.8	+ 2 54

It will probably be a fairly easy object this spring and summer. The other expected comets will come in reach of northern observers later in the year.

Williams Bay, Wisconsin, February 11, 1942.

Notes from Amateurs

The Cleveland Astronomical Society

Our February meeting held at the Warner and Swasey Observatory, on February 13, at 8:00 P.M. was a high spot in the winter series.

We were fortunate in having Dr. S. W. McCuskey who spoke on "Problems In Stellar Traffic." Slides throughout the entire lecture gave us visual understanding of the different subjects as the lecture progressed. A fine motion picture also illustrated galactic evolution. Dr. McCuskey is Assistant Professor of Astronomy at Case School of Applied Science. He has the rare faculty of presenting any subject, however difficult, so that the person of even limited technical background can get a good understanding of the matter. As an early experimenter in short-wave radio communication and later in the ultra-high frequencies, Dr. McCuskey developed the Star Counter—an instrument for the counting of stellar images on a photographic plate. So we here have a man who by his knowledge in another field was enabled to make this important contribution to the science of astronomy. As an original member of our Society we are very proud of Dr. McCuskey—pleasing friend and rising astronomer.

In the Exhibit Hall, transparencies, models, and instruments were shown as well as an interesting demonstration of the rotation of the earth by means of the Focault Pendulum. This work was under the direction of Mr. Jim Nassau, a student at Case and son of the Director of the observatory, Dr. J. J. Nassau.

After the meeting souvenir booklets of the observatory were presented to members and guests.

Dr. Nassau spoke of the contribution to defense being made by courses in Navigation and Optics at Case School of Applied Science and at the Observatory.

At the next meeting, March 13, at 8:00 P.M., the topic "Astronomy and the Spectroscope" will be discussed by Dr. Cedric E. Hesthal of Ohio State University.

If you wish to join The Cleveland Astronomical Society see Mrs. Royce Parkin, Secretary-Treasurer, The Cleveland Club, Cleveland, Ohio.

DON H. JOHNSTON.

Euclid Beach Park, Cleveland, Ohio.

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editor may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

Meteors and the Moon's Surface

[The writer of this note is in his ninety-fifth year, and has been a subscriber to POPULAR ASTRONOMY for many years. We congratulate him and commend him for his continuing interest in astronomy. He has brought this science prominently before the people of Duluth and vicinity through his private observatory there. EDITOR.]

The observed rapid cooling of the moon's surface during a total eclipse is taken to indicate that a layer of porous non-conducting substance covers the moon. Into this substance the sun's heat penetrates but a short distance and is rapidly radiated when the sun's heat is shut off by an eclipse. This is undoubtedly correct and has often been mentioned in textbooks and astronomical articles. The non-conducting substance is generally supposed to be a volcanic pumice.

It has occurred to me that the bombardment of meteors of the "shooting star" variety, on the moon, continued a very long time, might cause the indicated pulverization, instead of volcanic matter, or perhaps along with the latter. Here are some data relating to this question.

The number of small meteors striking the earth has been estimated at 24 million daily. These are caught by the atmosphere and burned up before reaching the ground. On the moon there are probably the same number of meteors striking a unit surface as on the earth, but with no atmosphere to interrupt their fall, and with a velocity probably around 26 miles a second the enormous energy per unit of mass is expended in crushing the rock which they strike and developing heat. The size of these meteors probably ranges from a boy's marble to coarse grains of sand.

As to the number of these meteors, or frequency, it is estimated as already stated that some 24 million of them strike the earth daily, and the same number per unit of surface strike the moon. First consider the earth. These 24 million meteors distributed uniformly over the earth's surface would be only one meteor to 8 square miles, an inconsiderable frequency. But during a possible two billion years of bombardment with the same frequency the total fall would be 3,210 meteors a square foot, and the total effect might pulverize a rocky surface to a depth, I should guess, of an inch or so; I cannot say how much this would be.

It should be remarked that the rate of fall of meteors was probably greater in the early period of the earth's history than at present, as during the two billion years of its history the planets have been sweeping up meteors and reducing their numbers. How much greater the fall was in former times is a matter of conjecture.

Another question arises: was the moon's origin contemporaneous and history similar to that of the earth? This I cannot answer. The presence of craters on the moon, probably of volcanic origin, would suggest that the meteoric effect of pulverizing the surface did not begin until after the craters were formed, and might shorten the period of their fall to considerably less than two billion years.

Another fact should be mentioned. Besides the meteors we see as shooting stars there are telescopic meteors of unknown size and number, perhaps something like fine grains of sand in size, which with their high velocity would have considerable abrasive effect upon a rocky surface and add to the pulverizing effect of the larger meteors.

It has been a surprise to me that I have not seen in any of the textbooks or astronomical articles which I have read any mention of the possible effect of meteoric bombardment of the moon's surface. But I have not read everything that has been written, by any means, and it is possible that this matter has been discussed by some astronomers.

The rate of fall of one meteor to 8 square miles daily, an area of about three miles square, would seem to only slightly endanger a human visitor to the moon, if we may suppose he should be able to get there and live without air or water. But I should not like to take even that small chance.

J. H. DARLING, *Director.*

The Darling Observatory, Duluth, Minnesota, February 6, 1942.

General Notes

Prof. Henry Norris Russell, research professor of astronomy at the University of Princeton, has been elected to an honorary fellowship at King's College, Cambridge. Prof. Russell, who is the doyen of American astronomers, graduated as Ph.D. at Princeton, after which he entered King's College, Cambridge, as an advanced student in 1902, and was in residence at Cambridge for three years. During that time he carried out research in collaboration with Mr. A. R. Hinks, now secretary of the Royal Geographical Society, upon parallax, and the methods they developed have become standards. This no doubt was a first step on the way to some of Professor Russell's most notable work. (*Nature,* January 3, 1942.)

The Rittenhouse Astronomical Society, of Philadelphia, held its regular meeting on Friday evening, February 13, in the Lecture Hall of the Franklin Institute. The speaker was Samuel G. Gordon, of the Academy of Natural Sciences, on the subject: "Some Recent Ideas Regarding the Earth."

Observations of Minima of Algol:—The following times (geocentric) of minimum of Algol, believed to be correct within six minutes, have been obtained from photographs taken at the Smith College Observatory and at the John Payson Williston Observatory of Mount Holyoke College on November 16 and November 19, respectively.

1941, November 16, $22^h\ 45^m$, E.S.T.
November 19, $19^h\ 32^m$, E.S.T.

The time interval between the observed minima ($2^d\ 20^h\ 47^m$) is two minutes less than the accepted period. The observation on November 16 is fifteen minutes earlier than the predicted time given in *The Observer's Handbook* published by The Royal Astronomical Society of Canada and fifty-seven minutes earlier than the predicted time given in *The Handbook of the British Astronomical Association.*

The following times (geocentric) of first minimum in each month of 1942 are based on the heliocentric minimum for November 16 and on the period of $2^d.867318$ derived by Smart.[1] These predictions supersede those given in a previous article.[2] All times are Eastern Standard.

	h	m		h	m
1942, Jan. 1,	19	50	1942, July 1,	11	21
Feb. 2,	8	52	Aug. 2,	0	17
Mar. 3,	1	5	Sept. 2,	13	11
Apr. 3,	14	7	Oct. 1,	5	17
May 2,	6	18	Nov. 1,	18	13
June 2,	19	16	Dec. 3,	7	11

This prediction for January 1 precedes by ten minutes that mentioned by Dr. Kopal in the February issue of *The Sky and Telescope*. Since his prediction is based on Hall's photoelectric observation, it should have the greater weight.

REFERENCES

[1] *M.N.*, **97**, 402, 1937. [2] *Pop. Astr.*, **50**, 21, 1942.

South Hadley, Massachusetts. MARY R. HUNT.

Astronomy and War Preparation

Following is a verbatim copy of an outline of emergency courses in astronomy and mathematics which I have just received from Professor C. C. Wylie. It represents the results of the work of a committee working under the American Association for the Advancement of Science, and in coöperation with the United States Army Air Corps. The committee consisted of Professors W. L. Hart (Minnesota), W. M. Whyburn (California at L.A.), and C. C. Wylie (Iowa).

DEAN B. MCLAUGHLIN, *Secretary*, American Astronomical Society.

ASTRONOMY

The emergency course in astronomy should emphasize quick identification of the stars and planets in the evening sky. It should include practice in reading a watch to the second, and numerous simple problems in time, longitude, and latitude, including the Sumner method. These problems should be simple, and many should be worked with the slide rule, or tables. The instructor should insist on quick work to three or four figure accuracy, and also on freedom from mistakes. The course should include more weather and climate than is given ordinarily, including identification of the chief cloud types. It should include an introduction to cartography, or map projections. It will be sufficient to give lectures of a popular type on many subjects taught in the usual course in astronomy.

The committee, and the Army officers working with the committee, did not plan that the schools should give work in the actual use of the sextants. A sufficient number of sextants to permit the actual use of them by any number of the emergency students could not be furnished to the schools. It seemed better to plan that the colleges give the underlying mathematics and astronomy, and the Air Corps itself teach the actual use of the sextants and the other navigational instruments.

A fuller description, and suggestions for the modification of regular courses to meet the emergency needs will be prepared and sent out at a later date.

MATHEMATICS

Algebra, emphasis on manipulative skill.....25 class hours
Plane Trigonometry and logarithms, with emphasis on slide

rule computation and on problems involving vector forces.....40 class hours
Solid Geometry, approximately.....25 class hours
Spherical Trigonometry, with emphasis on problems relating to latitude, longitude, and the astronomical triangle, approximately.10 class hours

A fuller description and suggestions for the modification of regular courses to meet the emergency needs will be prepared and sent out at a later date.

Book Reviews

The Internal Constitution of the Stars. (Annals of the New York Academy of Sciences, Vol. XLI, Art. 1.)

A series of papers presented at a conference on this subject held at the New York Academy of Sciences in October, 1939. Titles and authors are as follows:

Introduction to the Conference.....Harlow Shapley
Distribution of Density within the Stars.....Henry Norris Russell
Ellipticity and Reflexion Effects in Eclipsing Binary Systems.....Zdeněk Kopal
Radiative and Conductive Opacities under White Dwarf Conditions.....Robert E. Marshak
Stellar Envelopes.....Jaakko Touminen

This list does not include all papers presented at the Conference but only those not published elsewhere. The papers, for the most part, are highly technical and cannot be summarized properly for a popular review. Readers interested in the subjects discussed will find the papers of real value as contributions on certain points in the general problem of the internal constitution of the stars.

E.A.F.

Carleton College.

The Fundamental Properties of the Galactic System. (Annals of the New York Academy of Sciences, Vol. XLII, Art. 2.)

At a conference held at the New York Academy of Sciences in May, 1941, a series of papers was presented on some of the fundamental properties of our stellar system. Titles and authors are as follows:

The Reference System of Stellar Positions.....H. R. Morgan
The Reference System with a View to Planetary Dynamics.....Dick Brouwer
Mean Secular Parallaxes of Faint Stars.....P. van de Kamp
Mean Parallaxes from Peculiar Motions.....E. T. R. Williams
The Luminosity Function.....W. J. Luyten
The Magnitude Scale Today.....F. H. Seares
Stellar Distribution in High and Intermediate Latitudes.....B. J. Bok, D. A. MacRae
The Absorption Coefficient and the Luminosity Function in the Galactic Plane.....Jan Schilt

This series of papers aids greatly in bringing together the great amount of material published in recent years on the problem of directions in space; the distances, distribution, and brightness of the stars; the great problem of loss of light by absorption in various directions of space, etc. In order to understand the structure of our stellar system these various quantities must be known. These papers deserve careful reading.

E.A.F.

Carleton College.

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge the receipt of the following named publications and express their great appreciation of the courtesy shown on the part of those who have sent them.

Contributions from the Mount Wilson Observatory—

No. 644. "Displacements of Lines in the Spectra of Long-Period Variables," by Paul W. Merrill.

No. 645. "Absorption Spectra of Gases in the Extreme Ultraviolet," by Toshio Takamine and Yoshio Tanaka.

No. 646. "The Mean Absolute Magnitudes of Stars of Spectral Types O5-B5," by Ralph E. Wilson.

No. 647. "The Magnitude Scale of the Bright Polar Standards," by Frederick H. Seares.

No. 648. "Relative *f*-Values for Lines of *Ti*II," by Robert B. King.

No. 649. "The Radial Velocities of Long-Period Variable Stars," second paper, by Paul W. Merrill.

No. 650. "Selective Absorption in Space near the Sun," by Joel Stebbins, C. M. Huffer, and A. E. Whitford.

No. 651. "Temperature Classification of Thulium Lines," by Arthur S. King.

Contributions from the McDonald Observatory—

Nos. 24, 25, and 26. "The Spectrum of NGC 6543 and Its Nucleus," by P. Swings. "The Nebular Spectra of Two Slow Novae: DQ Herculis and RT Serpentis," by P. Swings and O. Struve. "The Spectrum of the Companion of *a* Scorpii," by O. Struve and P. Swings.

No. 27. "The Spectroscopic Binary 29-Canis Majoris," by Otto Struve and Frances Sherman.

No. 28. "On the Interpretation of β Lyrae and Other Close Binaries," by Gerard P. Kuiper.

No. 29. "The Spectrum of the Night Sky," by C. T. Elvey, P. Swings, and Walter Linke.

No. 30. "The Spectra of Two Peculiar Stars MWC 17 and CD —27° 11944," by P. Swings and O. Struve.

No. 31. "The Evolution of a Peculiar Stellar Spectrum Z Andromedae," by P. Swings and O. Struve.

No. 32. "The Light-Curve of the Eclipsing Variable 29 Canis Majoris," by Carl K. Seyfert.

No. 33. "The Spectrum of the Shell of Pleione," by Otto Struve and P. Swings. "The Visual Spectrum of Pleione," by Jesse L. Greenstein.

No. 34. "The Emission Lines in the Spectra of B 1985 and WY Geminorum," by P. Swings and O. Struve.

No. 35 "Studies of Faint B-Type Stars," by Carl K. Seyfert and Daniel M. Popper.

No. 36 "A Contribution to the Study of β Canis Majoris," by O. Struve and P. Swings.

No. 37. "Spectrographic Observations of Peculiar Stars. II," by P. Swings and O. Struve.

No. 38. "The Spectrum of Comet Cunningham, 1940 *c*," by P. Swings, C. T. Elvey, and H. W. Babcock.

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